CHAPTER 4

PROGRAM PLANNING

Active Microwave Users Working Group

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INTRODUCTION

The basic objective of the Microwave Program Planning Panel is to develop a detailed programmatic and technical development plan for active microwave technology in each of four user activities: (1) vegetation resources, (2) water resources, (3) mineral resources and geologic applications, and (4) oceanographic applications. This general objective is further defined in terms of the following specific objectives.

1. Identify major application areas.

2. Evaluate the impact of each application area in terms of social and economic gains and specify the technical requirements of the user community, including State and Federal agencies and the private sector.

3. Summarize the present state of knowledge of the applicability of active microwave remote sensing to each application area and evaluate its role relative to other remote-sensing devices.

4. Identify the analysis and data acquisition techniques needed to resolve the effects of interference factors in order to establish an operational capability in each application area.

5. Structure flow charts of accomplished and required activities in each application area that lead to operational capability.

6. Develop programmatic guidelines to support the applications development tasks.

In 1974, the NASA-sponsored AMW was held in Houston, Texas, "to review and define the anticipated advantages of active microwave systems in future Aerospace Applications Programs" (ref. 4-1). The final product of the workshop was a well-documented report that presented a comprehensive state-of-the-art review of the capabilities and limitations of active microwave sensors for providing the required information to user applications in each of three areas: (1) Earth/land, (2) ocean, and (3) atmosphere. The findings of the 1974 AMW were recently (July 1976) updated by an Active Microwave Task Team study in the form of a report that "reviews needs, applications, user support, and empirical research and theoretical studies with imaging radar" (ref. 4-2).

In preparing the program plan contained in this report, the Program Planning Panel relied heavily on the contents of the AMW and the Active Microwave Task Team reports (refs. 4-1 and 4-2, respectively), as well as on the microwave program plan charts prepared by Dr. John Rouse for NASA Headquarters.

Incorporated in the approach taken by the Program Planning Panel to meet its objectives were the following considerations.

1. The 16 panel members, experienced engineers and scientists in active microwave remote sensing, were selected such that all four application areas of interest (vegetation resources, water resources, mineral resources and geologic applications, and oceanographic applications) were well represented.

2. The program plan developed for each application area - which included laboratory, ground-based, airborne, and spaceborne experiments, as well as models and analysis techniques development - was structured in such a way as to make maximum use of Seasat to test parameters of interest and to lead to operational capability on the Space Shuttle, if feasible.

3. Emphasis was placed on sensing parameters with a wide range of applications (e.g., soil moisture for crop yield prediction, runoff prediction, detection of locust breeding grounds in arid environments, etc.) and on developing techniques applicable over large parts of the world.

4. Test sites were carefully selected to serve (where feasible) more than one application so that maximum use could be made of time, funds, equipment, and personnel. Moreover, test site selection was coordinated with that of the Seasat Land Experiments Panel.

5. Evaluation was made of the total sensor package required for each application; the relative role of each sensor was indicated.

VEGETATION RESOURCES PROGRAM PLAN

Introduction

Cultivated and natural vegetation plays a vital role in man's everyday activities and in the economic health of a nation. The wise management and conservation of these resources is of concern to the farmer, rancher, forester, and consumer; to several State and Federal agencies having regulatory functions; and to nations determining international policy in this respect. The need to inventory and monitor large areas over relatively short periods of time can be met feasibly only by the use of spaceborne remote sensors, although the need for supplementary field data from selected sample sites will probably always exist. Despite the great potential of Landsat photographic imagery, there is, in the area of vegetation resources, need for incorporation of active microwave sensors into an Earth resources observation program.

The primary vegetation-related applications of active microwave sensors as identified by this panel are as follows.

1. Monitoring soil moisture for purposes of estimating crop yield and predicting outbreaks of locusts and other insects whose life cycles are related to soil moisture

2. Identifying, mapping, and inventorying areas of vegetation, both natural and cultivated, for estimating productivity and for managerial purposes

3. Monitoring vegetation moisture content for detecting insect infestations or diseased plants, for estimating crop vigor and yield, and for detecting potential fire hazards

4. Detecting, mapping, and monitoring saline seeps in agricultural areas

5. Mapping general soil types and detecting deleterious soil conditions such as mineralized soils, claypans, blowouts, etc.

In view of the aforementioned applications, it is important to delineate the primary goals of a comprehensive investigation of an active microwave sensor as applied to vegetation resource management. These goals are as follows.

1. Information needs and availability: To make maximum use of time and resources, determining the observational requirements of the ultimate users of an active microwave sensor is necessary. Subsequent to such a determination, ascertaining the ability or inability to extract such information from data generated by an active microwave sensor will be necessary.

2. Information model compatibility: Although active microwave data may directly supply the user with immediate information, such data will probably be used in conjunction with data supplied by other sources. It is important to determine that microwave observations are indeed complementary to nonmicrowave observations and that such data can be successfully incorporated into existing biological/agricultural models. Moreover, it should be shown that, as a result of this incorporation, data quality is substantially improved and/or data are generated at a substantially faster rate because of the availability of radar observations.

3. Applications systems verification test (ASVT): Before the final development of an operational active microwave observational program, the

sensor-model-user system should be evaluated in a semioperational environment. As specified by NASA, this directive implies system evaluation in an ASVT.

Critical to the development of an operational active microwave Earth observation program as applied to vegetation resources is the generation of a data base acquired from a broad range of vegetation classes during a variety of plant development stages. Being governed by the rate of plant development, this data collection process is time consuming. Whereas it may seem that 4 months of data collection are adequate to determine the scattering properties of a cornfield, for example, it must be realized that factors such as climate, planting practices, and differing plant varieties will introduce considerable variance into such scattering data Thus, a single cornfield should be observed for a number of years before its scattering properties are absolutely determined.

Although statements such as these may seem to present a pessimistic view of the status of the generation of a data base on the radar response to vegetation, it must be remembered that programs to gather the needed data have been ongoing for more than a decade. The inherent dynamics of vegetation necessitate, however, that more investigative work be conducted. In table 4-1, the status of the present knowledge on the radar response to vegetation is placed in perspective; and in table 4-2, a detailed breakdown of the major variables affecting the active microwave response in each of the application areas is presented.

Approach

Soil moisture monitoring through vegetation.- Many crop yield models now utilize soil moisture data rather than rainfall data (ref. 4-3). Because radar, unlike the photographic sensors, is highly sensitive to soil moisture conditions, it may become the prime source of information on this important parameter. Landsat imagery, however, could still provide supportive data. Because soil/water physics is essentially the same worldwide, with allowance for local variations in soil type, topography, etc., basic techniques worked out for localized test sites can be expanded and improved for use from spaceborne platforms.

The influence of complicating effects such as frozen and thawed soil states, snow cover, and vegetation cover has yet to be clearly understood. Through the development of such an understanding, it seems reasonable to expect to be able to employ radar data to monitor soil moisture conditions for input into yield models for cropland and rangeland. (Because microwaves will not penetrate to the soil through dense forest canopies, sensing vegetation moisture will be limited to mapping cover types.) Such data are also of value to hydrologists for flood prediction and water resource management. Moreover, the same data would aid in the prediction of conditions conducive to an outbreak of insect pests or plant pathogens whose life cycles and relative abundance are closely tied to the soil moisture regime. Many sensors necessary for air- and ground-based experiments have been developed and are available. Enough ground-based radar experiments have been completed to indicate that fallow fields for the following radar parameters appear optimal for an operational soil moisture mapping

TABLE 4-1.- VEGETATION RESOURCES APPLICATIONS SYSTEMS REQUIREMENTS

Application	Role[a]			Wave-length, cm	Interpretation resolution, m		Nadir angle, deg	Polar-ization type	Revisit interval	Status[b]	Priority[c]	Comments
	Active microwave	Passive microwave	Visible/IR		Desire	Accept						
Soil moisture for yield estimate												Extremely signifi-cant, unique capability
Cultivated	P	P	S	6 to 8 and 1.7 to 2.2	90	200	7 to 17	HH and cross	1 to 7 days DGS[d]	SE	VH	
Natural/range	P	P	S	6 to 8	90	200	7 to 17	HH and cross	1 to 7 days	PS	VH	
Natural/forest	S	S	S	5 to 30 MF[e]	90	200	7 to 17	HH and cross		UT	L	
Vegetation identification and mapping												All-weather com-plement to vis-ible data
Cultivated	P	N	P	.8 to 3 MF[e]	30	90	40 to 60	HH/VV/cross	10 days DGS[d]	SE	VH	Limited experi-mentation to date
Natural/range	P	N	P	.8 to 3 MF[e]	30	90	40 to 60	HH/VV/cross		PT	M	
Natural/forest	S	N	P	.8 to 3 MF[e]	30	90	40 to 60	HH/VV/cross	Seasonally	PS	H	
Vegetation mois-ture monitoring												Unique capability
Cultivated	P	N	S	.8 to 5 MF[e]	30	90	40 to 60	HH/VV/cross	10 days DGS[d]	SE	VH	
Natural/range	P	N	S	.8 to 5 MF[e]	30	90	40 to 60	HH/VV/cross		PT	M	
Natural/forest	P	N	S	.8 to 5 MF[e]	30	90	40 to 60	HH/VV/cross	Seasonally	PT	H	
Saline seep moni-toring	P	S	S	3 to 30 MF[e]	30	200	7 to 17	HH/VV/cross	Seasonally	PT	VH	New application
Soil mapping	S	S	P	.8 to 30 MF[e]	90	200	CS[f]	CS[f]	Event determined		M	Limited experi-mentation to date

[a]The role symbols are defined as follows.
P - prime sensor
C - complementary sensor
S - supportive sensor
N - not needed

[b]The status symbols are defined as follows.
PC - proven capability
SE - strong evidence of capability
PS - potential suggested by experimentation
PT - potential suggested by theory or analogy
UT - under test

[c]The priority symbols are defined as follows.
VH - very high priority and feasibility
H - high priority and feasibility
M - medium priority and feasibility
L - low priority and feasibility

[d]DGS - during growing season.

[e]MF - multifrequency.

[f]CS - cannot be specified at this time.

TABLE 4-2.- STATUS OF ACTIVE MICROWAVE PROGRAM IN VEGETATION RESOURCES APPLICATIONS

(a) Soil moisture monitoring,[a] vegetation identification and mapping, and vegetaion moisture monitoring[b]

Variable	Theoretical modeling and laboratory experiments			Ground-based experiments			Aircraft experiments			Spacecraft experiments		
	Cover			Cover			Cover			Cover		
	Cultivated	Range	Forest	Cultivated	Range	Forest	Cultivated	Range	Forest	Cultivated	Range	Forest
Vegetation dielectric properties	1	1	--	N	N	N	N	N	N	N	N	N
Vegetation attenuation	1	--	--	1	--	--	N	N	N	N	N	N
Soil moisture	2	1	--	2	1	--	1	--	--	--	--	--
Soil type	1	1	--	1	1	--	1	--	--	--	--	--
Soil roughness	1	1	--	2	1	--	1	--	--	--	--	--
Plant moisture	1	1	1	2	--	--	--	--	--	--	--	--
Vegetation density	1	1	1	2	--	--	--	--	--	--	--	--
Row direction	1	N	N	2	N	N	1	N	N	N	N	N
Diurnal cycle	--	--	--	1	--	--	--	--	--	--	--	--
Crop or forest type	1	--	1	2	--	1	1	--	1	--	--	1
Stress (disease)	--	--	--	1	--	--	--	--	--	--	--	--
Mechanical damage	--	--	--	--	--	--	--	--	--	--	--	--
Wind	1	--	1	1	--	1	1	--	1	--	--	--
Freeze/thaw state	--	--	--	--	1	--	--	--	--	--	--	--
Snow cover	--	--	--	--	1	--	--	--	--	--	--	--
Temporal variation	--	--	--	3	--	1	1	--	--	--	--	--

(b) Saline seep monitoring

No active microwave data have been acquired of saline seeps. Preliminary laboratory tests have been conducted to measure the effects of salt content on the soil dielectric properties.

(c) Soil mapping[b]

Variable	Theoretical modeling and laboratory experiments	Ground-based experiments	Aircraft experiments	Spacecraft experiments
Soil dielectric properties	3	N	N	N
Soil type	N	--	1	--
Soil roughness	3	3	1	--
Soil moisture	3	3	1	--
Freeze/thaw state	1	1	--	--
Mineralization	1	--	--	--
Vegetation cover	1	--	1	--

[a]See table 4-5 (water resources).
[b]The table symbols are defined as follows.
N = not applicable
-- = no data acquired to date
1 = <35 percent of needed data acquired to date
2 = 35 to 65 percent of needed data acquired to date
3 = >65 percent but <100 percent of needed data acquired to date
\+ = data collection complete

system: frequency = 4 GHz, angle-of-incidence range = 7^0 to 17^0, and polarization = HH. Adequate interpretation techniques and data-processing methods also exist except for the case of irrigated terrain. However, a considerable amount of laboratory and theoretical investigation plus followup fieldwork remains to be done. The proposed program plan for this application is covered in detail in the "Water Resources Program Plan" section.

Vegetation identification and mapping, and vegetation moisture monitoring.- Applications relating to direct observation of the Earth's vegetation cover may be divided into two broad categories. One category involves the identification of the crop species, range type, or forest type, and the mapping and measuring of the area involved. The second category is concerned with a more precise determination of the moisture content of the plant and the manner in which this parameter reflects crop maturity or stresses due to moisture deficit, insect infestations, plant pathogens, or other sources. Both types of applications, however, can be investigated in the same set of experiments, and the comments in this section apply to both.

Improvement in the ability to recognize and inventory specific crop or natural vegetation types and also to detect vegetation cover conditions from a spaceborne platform can be translated into economic benefits along several routes, as follows.

1. The cost of producing crop forecasts can be reduced. At present, the U.S. Government spends $40 million per year on such forecasts.

2. Crop forecast accuracy can be improved. According to Hayami and Peterson (ref. 4-4), each 1-percent error in such forecasts costs $300 million, partially because of incorrect decisions regarding grain exports and other factors that affect grain prices.

3. Detection of stresses due to various causes provides further input into yield calculations. It also warns that remedial action (application of herbicides, fire hazard warnings, etc.) should be taken if possible; thus, further savings are achieved by reducing losses due to insect infestation, forest fires, etc.

4. A more accurate inventory of natural resources is also of considerable value in making long-term decisions or defining long-term goals with regard to management of Federal lands such as national forests.

Most microwave research to date has focused on a few major U.S. crops - wheat, corn, grain sorghum, soybeans, and alfalfa - and most of this work has been ground based. Results of these studies have been significant and indicate strongly the direction that future research should take with regard to sensor parameters. Briefly, the following facts have been determined (refs. 4-5 to 4-7).

1. Plant geometry, density, and water content affect radar backscatter.

2. Radar backscatter varies significantly with the biophase of crops.

3. Maximum correlation between radar backscatter and vegetation characteristics occurs for wavelengths less than 3 cm and incident angles greater than 45^{o}.

4. With multidate data obtained with a frequency of coverage of approximately once every 10 days, corn, wheat, milo, soybeans, alfalfa, and bare ground can be separated with better-than-90-percent-correct classification. Specifically, after 30 days of sampling (at 10-day intervals), with 14-GHz dual-polarized (VV and HH) data, the aforementioned crops can be classified with better-than-95-percent accuracy (ref. 4-7).

5. Leaf area index and row direction affect radar backscatter, especially early in the growth cycle. The effect of row direction is minimal above 8 GHz.

6. Radar response to vegetation varies over the diurnal cycle; however, the effects are minimal above 8 GHz.

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Theoretical modeling and laboratory experiments.

a. Measurements of the dielectric constant effects on plant matter with respect to vegetation type, stage of growth, and moisture content should be performed. These data should subsequently be used to determine an effective dielectric constant for a cultivated field.

b. Backscatter models of vegetation canopies should be developed, not only to aid in relating radar data to vegetation characteristics of interest to users but also to aid in developing a basic understanding of electromagnetic scatter from plant communities.

2. Task B - Ground-based experiments.

a. Cultivated crops - Microwave observations of cultivated crops should be continued with the following objectives in mind: (1) development of data base of detailed phenological observations of specific vegetation types, (2) development of crop identification schemes in which microwave data inputs are used, and (3) collection of detailed observations of crop types, with emphasis placed on crop stress detection. Such objectives could be met by continuing controlled, ground-based MAS studies for integration with data from other active and passive sensors on aircraft.

(1) Sensors - The 8- to 18-GHz MAS (Kansas University), C- and K-band scatterometers (JSC), and an X-band imager (JSC's RB-57F or the JPL Convair 990).

(2) Availability of needed sensors - All are presently available. Additional 8- to 18-GHz truck-mounted systems are desired in Texas and/or California to increase efficiency and speed of ground-based studies.

(3) Test sites -

(a) Fiscal year (FY) 1977 to 1978 - Garden City area, Finney County, Kansas - LACIE super site, cropland and range.

(b) FY 1978 to 1980 - Grand County, Colorado - LACIE super site, range and forest.

(c) FY 1978 to 1981 - Eventually expand to other sites in United States - California, Idaho, Montana, Pennsylvania, etc. (see fig. 4-1) - and other countries.

(4) Ground-truth support - Soil moisture profiles, bulk density profiles, soil roughness, plant type, row spacing, row direction, crop height, moisture, etc.

(5) Frequency of data collection - Every 9 days, coincident with overflights by Landsat-1 and -2; total of 18 missions each season.

b. Forest lands - Microwave observations of forest land should be initiated to determine relationships between radar return and forest type, canopy structure, vegetation moisture content, and site parameters. It is suggested that such investigations begin with ground-based experiments in which the University of Kansas 8- to 18-GHz MAS is used in the Missouri Ozarks, with initial emphasis on empirical observations of differences in backscatter from coniferous versus broadleaf tree types and of temporal variations in vegetation moisture content. If possible, data will also be collected for trees damaged by sulfur dioxide gas from lead smelters in the vicinity.

(1) Sensors - An 8- to 18-GHz ground-based radar.

(2) Sensor availability - Available.

(3) Test site - Pine-oak-hickory forests in the St. Francois Mountains of eastern Missouri, on land belonging to Clark National Forest and also in the general vicinity of a new lead-mining region (the Viburnum trend).

(4) Frequency of data collection - Seasonally.

3. Task C - Aircraft experiments. An extensive airborne microwave response data acquisition program should be initiated as soon as feasible. The main advantage of such a program would be that of data collection over widely varying vegetation conditions. Such data are badly needed to confirm or refute conclusions reached after analyses of the data gathered on a local basis by ground-based systems.

a. Sensors -

(1) Ground - An 8- to 18-GHz ground-based radar.

(2) Airborne - L-band, C-band, and Ku-band JSC scatterometers.

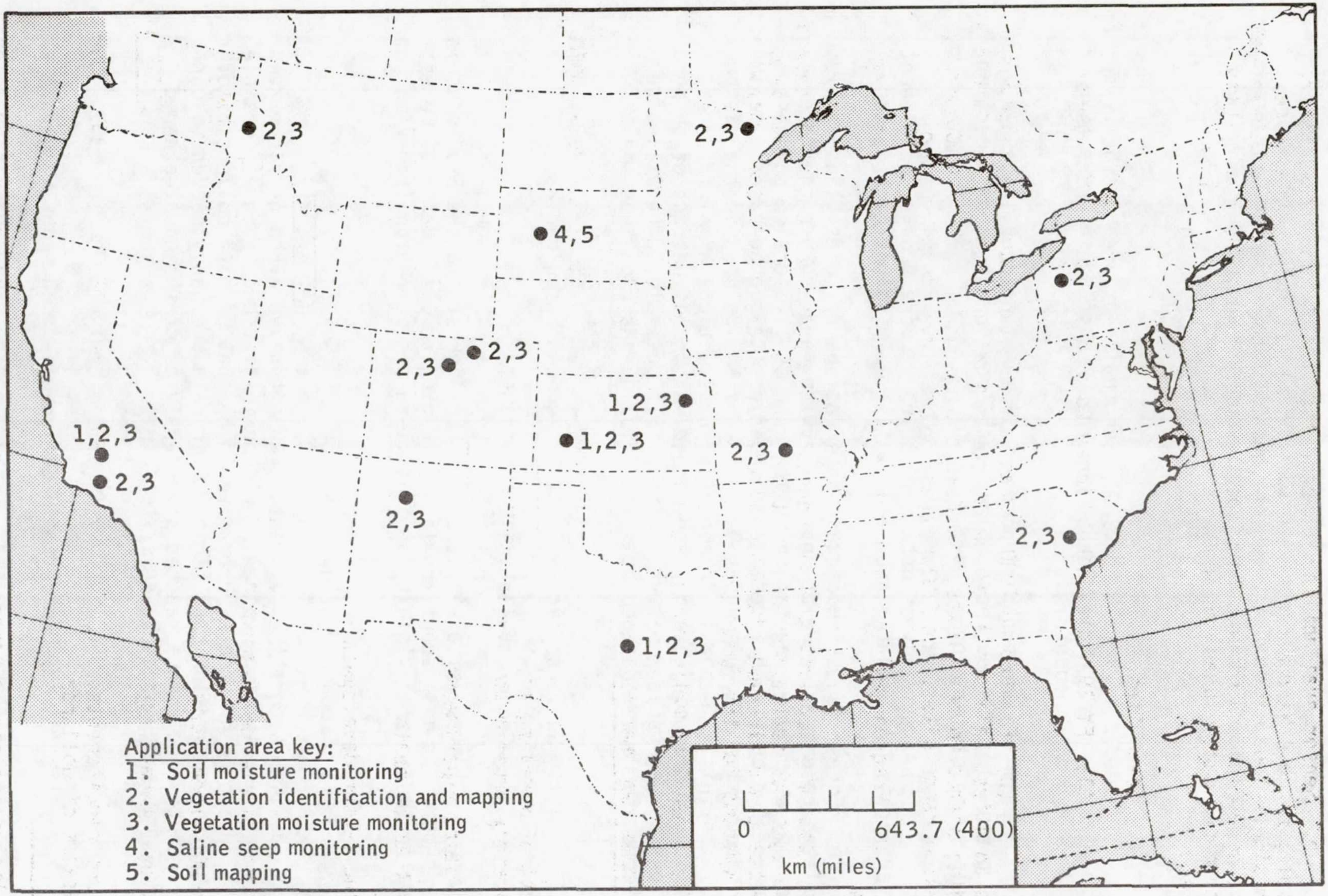


Figure 4-1.- Vegetation resources applications test sites.

b. Sensor availability - L-band and K-band scatterometers are available; but a C-band radar system with 5° to 20° nadir angle range, 12.5-m single-look resolution, and HH- and cross-polarization capabilities must be developed. Although, for experimental purposes, the JSC K-band scatterometer can be used, an imager should be developed for ASVT purposes.

c. Test sites -

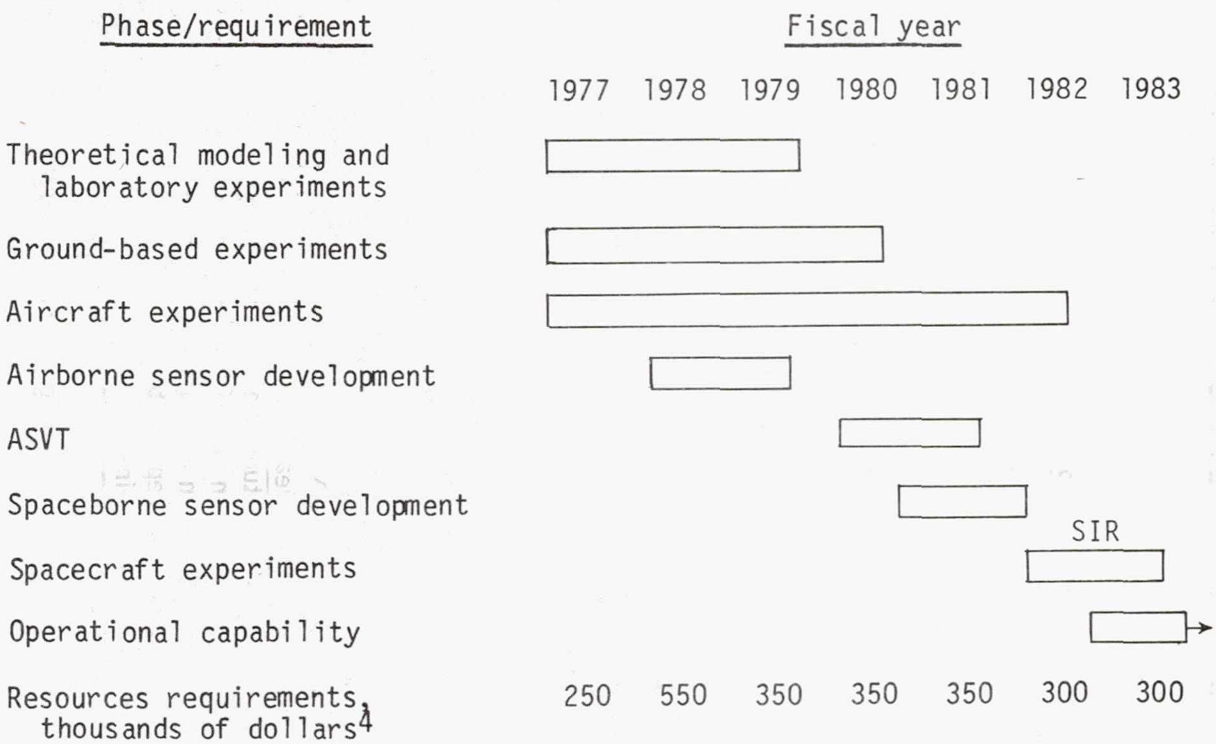
(1) FY 1977 to 1979 - Finney County, Kansas - LACIE super site.

(2) FY 1978 to 1980 - Grand County, Colorado, and Kern and Plumas Counties, California, are being considered. Sites in other States - including Brazos County, Texas, the Pawnee grasslands in eastern Colorado, New Mexico range sites, and Idaho forest sites - may be added also.

d. Frequency of data collection - Nine days during the growing season.

4. Task D - Spacecraft experiments. It is premature to detail experiment designs for spacecraft at this time. However, knowledge gained from ground-based and aircraft studies will enable the development of optimal sensor systems for the Space Shuttle.

The scheduling relevant to these tasks is as follows.



[4]Includes airborne sensor development but not spaceborne sensor development.

Saline seep monitoring.- A saline seep is a terrain area with extremely high salt concentration at the soil surface, caused by the transport of excess water through salty upper strata underlain by impermeable layers, usually salt-laden shales. In the north-central plains, seep formation is aggravated by the every-other-summer dryland fallowing practice used to conserve water.

Approximately 590 517 km^2 (228 000 mi^2) in the Wheat Belt zones in the Dakotas, Montana, Alberta, Saskatchewan, and Manitoba are potential saline seep areas. Similar areas have also become evident in various parts of the world. From 1969 to 1974, there has been a 300-percent increase in the saline seep area in Montana, where the biennial wheat losses are valued at approximately $50 million.

Saline seep areas can sometimes be improved by deep plowing. If potential seep areas can be identified early, alfalfa or similar vegetation can be planted, with the result that evapotranspiration will be increased and the buildup of salts at the surface prevented. The objective of this application is to develop the technique for early identification and mapping of saline seep areas so that early preventive measures may be taken.

For this particular application, active microwave is considered the prime sensor, although passive microwave and visible/IR sensors will provide complementary data.

Direct methods of identifying potential seeps and the location of active seeps include (1) a four-probe soil conductivity technique and (2) the refraction seismographic method. These methods are useful tools but require enormous expenditures of time and labor.

High-water tables in the seeped areas have an influence on the surface thermal properties, as well as on the growth patterns of indicator plants that can provide detectable thermal IR and visible signatures. Experiments are in progress that use change detection procedures to give an estimate of the rate of increase or decrease of seeped areas; in addition, specialized imagery enhancement techniques - e.g., density slicing - are being used to attempt a separation of seep areas from nonseep areas.

Ongoing research indicates that thermal IR is useful in defining the spatial extent of surfaces of high evaporation in a normally dry region and thereby in predicting areas of potential seeps. However, this interpretive technique is necessarily complex because it depends on the dynamics of soil evaporation; and whereas some spatial information is provided, seep severity cannot be quantified because the visible/IR reflectivity is not uniquely dependent on soil salinity.

The identification of potential seeps by using complementary microwave and visible/IR imagery should be possible because the microwave response (either scattering cross section or emissivity) is much less sensitive to soil thermal profiles and much more sensitive to dielectric constant as compared to thermal IR.

Preliminary laboratory measurements of saline-seeped-soil dielectric constants have been made, and a relationship has been established between soil salinity levels and their effects on the growth of crops such as wheat and barley. In addition, calculations have been made for expected passive and active signatures. Laboratory work and fieldwork are required on scattering cross sections and the modeling of surface roughness and to establish optimum frequency, polarization, look angle, etc. Necessary sensors - i.e., the Kansas University MAS and possibly the Texas A. & M. University passive radiometer - are available, together with airborne scatterometers, radiometers, and imaging radars. Algorithms permitting the separation of moisture effects from salinity effects on radar backscatter have not yet been developed.

Aircraft experiments in which scatterometers and radiometers are used will be required as an extension of the ground measurements program. Aircraft SAR flights would be a follow-on activity to establish the techniques for large-area detection and mapping of the saline seep areas. Sensor development requirements for the aircraft program will be dependent on the results of the ground-based experiments with regard to the optimum frequency, polarization, etc. Early results indicate that a multiple polarization system operating at L- or C-band may be the optimum. Existing and/or proposed scatterometers and SAR's will satisfy this requirement.

Global identification, mapping, and monitoring of saline seep areas is the ultimate objective, which can only reasonably be achieved with spacecraft systems. Spacecraft experiments to establish the specific instrument parameters and techniques are essential precursors to an operational capability.

On the basis of the preliminary ground measurements that indicate L-band as being a suitable frequency, data from the Seasat SAR will provide an early opportunity to evaluate the utility of a spacecraft system for saline seep mapping. The look angle and spatial resolution of that system are also supportive of this requirement.

A spacecraft system such as the proposed SIR will be required in order to fully evaluate the technique from space. The dual frequency, dual polarization, wide-swath coverage and variable-look-angle capability, as proposed for the SIR, will be essential to establish the parameters for an operational system. Because the frequency-of-coverage requirement for saline seep monitoring is low, it is possible that periodic flights with the SIR or similar Shuttle system could satisfy the operational needs.

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Theoretical modeling and laboratory experiments. A program for measuring the dielectric properties of salt-laden soil should be vigorously pursued. Dielectric content should be measured as a function of salt content, moisture content, and frequency.

2. Task B - Ground-based experiments. Ground-based studies to determine microwave signatures characteristic of particular soil types and terrain conditions should be initiated. Results of studies by Ulaby and associates at the University of Kansas on soil moisture and roughness

effects on backscatter and of studies by de Loor (ref. 4-8) in the Netherlands will be applicable to these studies. Of major interest in such investigations should be the effect of salt content on the radar response. Ground-based studies should be followed by aircraft studies, and microwave imagery eventually should be combined with photographic imagery. A wide variety of radar frequencies will be needed to test the theoretical relationships between soil and sensor parameters.

a. Sensors - The 1- to 8-GHz and 8- to 18-GHz ground-based radar systems and a JSC L-band truck-mounted radiometer.

b. Sensor availability - All sensors are available.

c. Test sites -

(1) FY 1978 to 1979 - Harding County, South Dakota, and Dickinson, North Dakota.

(2) FY 1979 to 1981 - The Highwood Bench and Rapelje, Montana.

3. Task C - Aircraft experiments. With the use of L-band, C-band, and ultrahigh frequency (uhf) scatterometers on the JSC C-130 aircraft and the MFMR on the JSC NP-3A aircraft, the objective of the airborne experiments is to determine the active and passive microwave response to (1) average seep salinity, (2) soil moisture, (3) frequency, (4) polarization, and (5) look angle; also, with use of the JPL L-band SAR imager, to determine image characteristics of seeped areas.

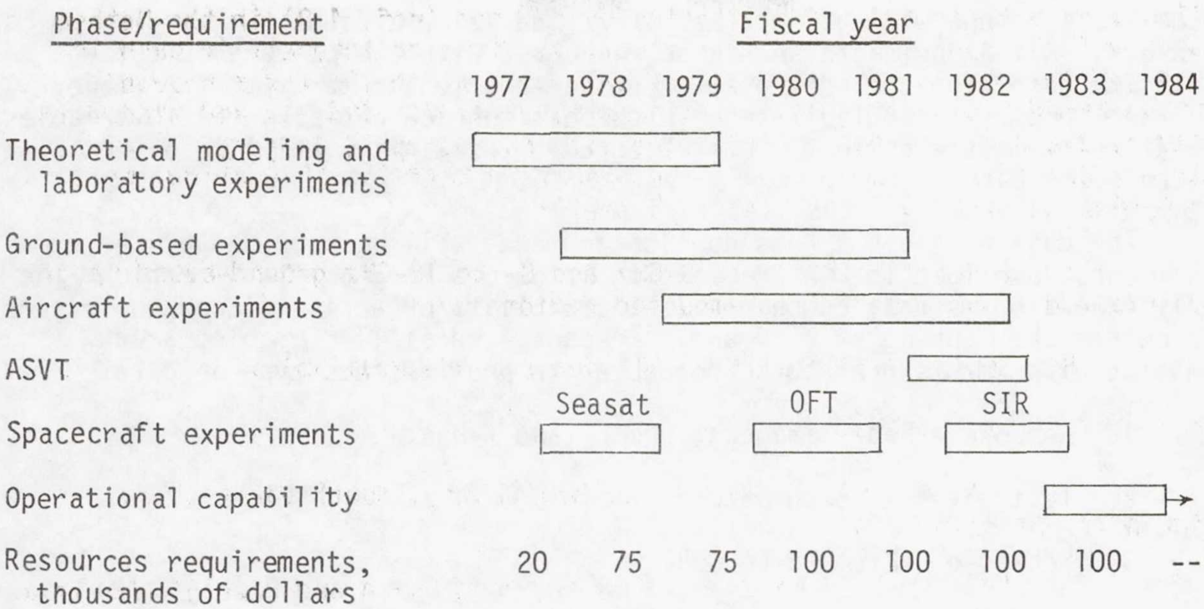
a. Sensors - NASA JSC L-band, C-band, and uhf (0.4 GHz) scatterometers; JPL L-band SAR imager.

b. Availability of sensors - JSC L-band and uhf scatterometers and JPL SAR are presently available; NASA JSC C-band scatterometer is expected by October 1977.

c. Test sites - (See task B, ground-based experiments.)

d. Data collection frequency - Once in April-May period and once in September-October period.

The scheduling relevant to these tasks is as follows.



Soil mapping.- Limited investigations (refs. 4-9 and 4-10) conducted in a range of environments indicate that active microwave has the capability for generalized soil discrimination. Radar imagery could provide the soil scientist with preliminary information for selected geographic regions to determine whether conventional detailed mapping is desired. Detection of localized problem areas such as claypans, plowpans, blowouts, etc., would provide supplementary data for the Federal LACIE, the U.S. SCS, and similar State and Federal agencies and programs. Detection of unused land suitable for cultivation or grazing and the determination of the engineering characteristics of soil (i.e., suitability for construction sites, etc.) could be especially advantageous in remote or undeveloped regions where extensive ground observations would be prohibitively expensive and time consuming. Because differences in soil makeup are frequently accompanied by parallel differences in water-holding capacity, multidate radar observations can be used to detect regions of differential drying rates. This difference may also be reflected in the vegetation cover, because plant community composition differs between mesic and xeric sites. The interpretation resolution required will, of course, depend on the end product desired - small-scale regional soil maps or large-scale, more localized maps. Although radar imagery can provide some soil information not extractable from photography, the converse is also true (ref. 4-11). Useful information is also obtainable from passive measurements, and it is likely that all three sensors - especially active microwave and photography - will continue to be desirable for soil mapping.

Only limited experimentation with this application has been performed to date. Additional research is required to develop quantitative interpretation techniques correlating microwave signatures and various environmental parameters such as surface roughness, soil moisture, and vegetation cover. Preliminary ground-based experiments with the University of Kansas truck-mounted MAS systems or similar systems for determining optimal frequency and incident angle will be necessary, together with laboratory measurements of the dielectric properties of various soil types. Followup aircraft flights for field checking ground-based studies and associated model development will be necessary for finalizing designs for spaceborne sensors. All experiments should be conducted with the primary objective being to determine the interplay among various sensor parameters (frequency, incident angle, and polarization) with soil surface and subsurface variables (texture, moisture content, vegetation cover, salinity, etc.) in determining radar backscatter.

The data needed for this application area will be provided by the experiments described in the "Vegetation Resources Program Plan" section. The only exception is data concerning the capability of active microwave sensors to enable the mapping of claypans, plowpans, and similar problem areas; imaging experiments need to be conducted to provide this type of data.

1. Sensors - Radar imagers, JPL L- and X-band

2. Test sites - South Dakota

3. Schedule - FY 1978 to 1980

4. Resources requirements - $25 000 per year

Development Plan

Figure 4-2 is a vegetation resources applications development plan, in a flow chart format, summarizing the major steps between the present status of each application area and the ultimate goal - i.e., operational capability. The associated schedules of ground-based, aircraft, and spacecraft experiments for each of the major application areas are summarized in figure 4-3, the corresponding resource requirements are summarized in table 4-3, and the test site locations are indicated in figure 4-1, presented earlier in this section.

Summary and Recommendations

The major application areas were rated with respect to priority and feasibility as follows.

Very high:

1. Soil moisture monitoring for crops and rangeland

2. Crop identification and inventorying

3. Crop moisture and health monitoring

4. Saline seep detecting and monitoring

High:

1. Forest community identification and inventorying

2. Forest moisture and health monitoring

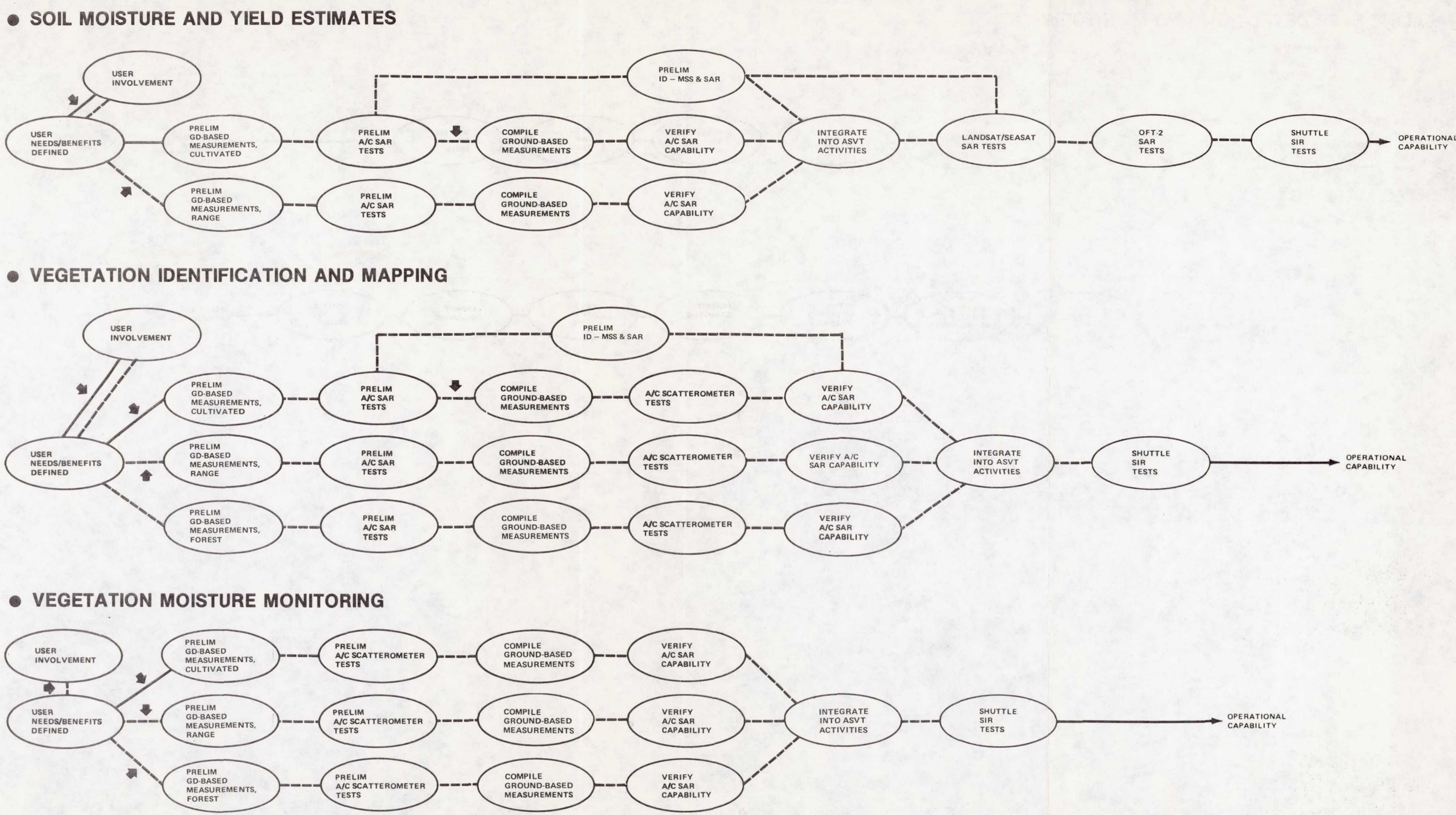
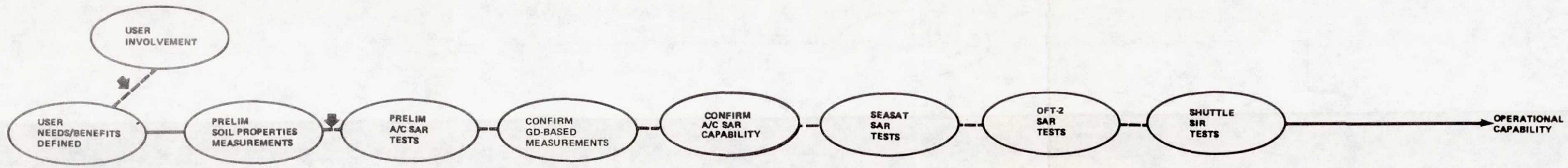


Figure 4-2.- Vegetation resources development plan.

SALINE SEEP DETECTION AND MONITORING



SOILS MAPPING

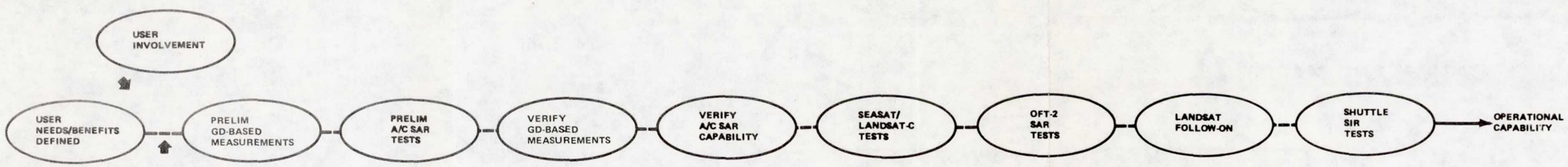


Figure 4-2.- Concluded.

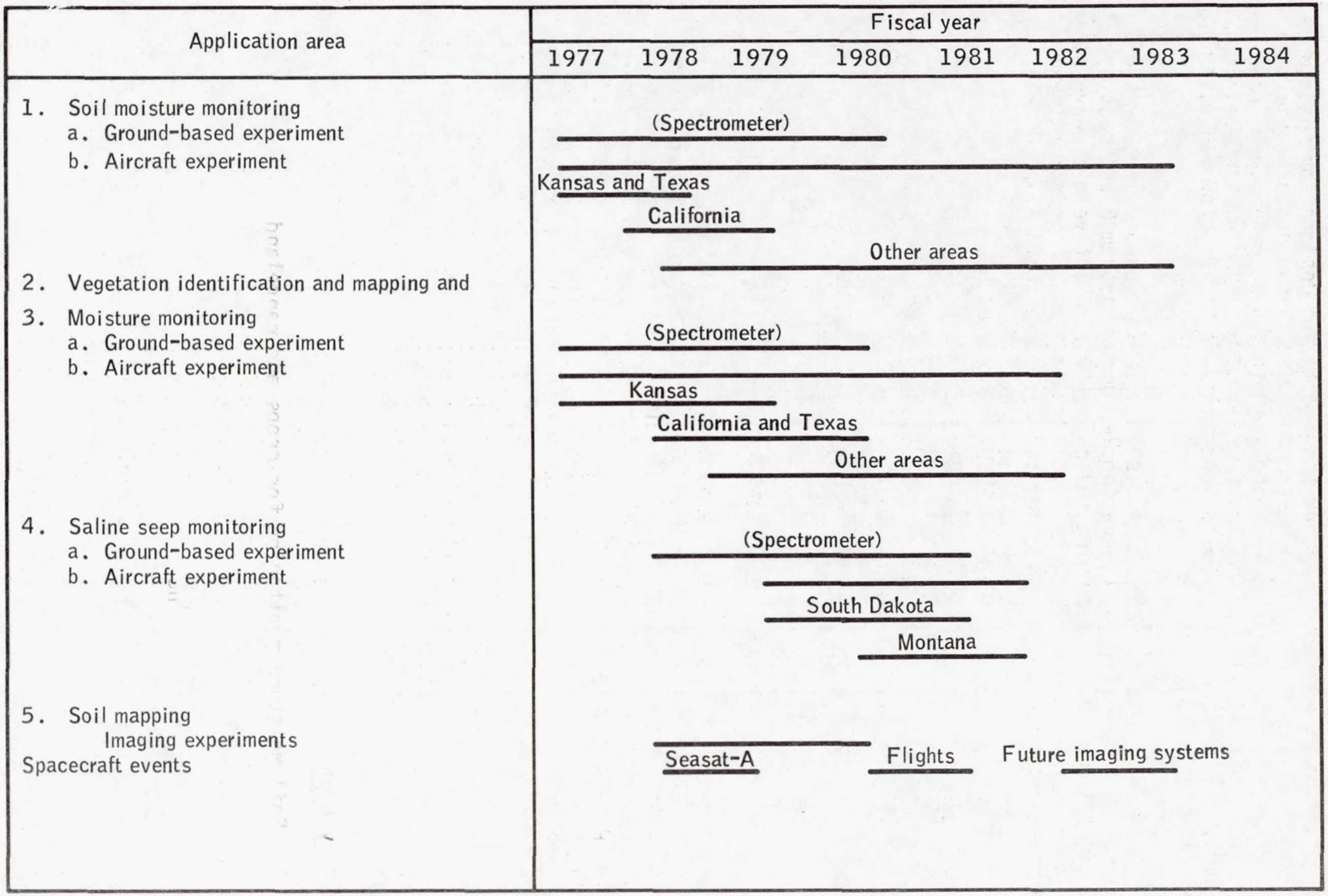


Figure 4-3.- Vegetation resources/active microwave activities.

TABLE 4-3.- VEGETATION RESOURCES FUNDING REQUIREMENTS

Application area	Fiscal year						
	1977	1978	1979	1980	1981	1982	1983
Soil moisture monitoring, vegetation observations	$300 000	$550 000	$350 000	$350 000	$300 000	$300 000	--
Identification and mapping Moisture monitoring	250 000	550 000	350 000	350 000	350 000	300 000	$300 000
Saline seep monitoring	20 000	75 000	75 000	100 000	100 000	100 000	100 000
Soil mapping	--	25 000	25 000	25 000	--	--	--
Total resources[a]	$270 000	$650 000	$450 000	$475 000	$450 000	$400 000	$400 000

[a]Resources for the soil-moisture-monitoring task are already included under the water resources; hence, they will not be included here.

Medium: Monitoring of erosion, hardpans, plowpans, and other deleterious properties in agricultural areas

Low:

1. Soil reconnaissance mapping

2. Soil moisture monitoring in forested areas

The recommendations are as follows.

1. The development of additional multifrequency, multipolarization radar spectrometers to supplement the existing 1- to 8-GHz and 8- to 18-GHz MAS systems at the University of Kansas should be pursued vigorously.

2. Airborne radar studies over natural and cultivated vegetation should be expanded.

3. Additional data must be gathered immediately to further define suitable specifications for a Shuttle radar optimized, at least in part, for vegetation and soil moisture studies. At this time, a dual frequency (approximately 4 and 14 GHz), dual polarization (HH and VV) radar seems optimal for soil moisture and vegetation data.

WATER RESOURCES PROGRAM PLAN

Introduction

Many agencies on all levels (Federal, State, and local) have responsibilities for water resources management. It is estimated that $12 to $15 billion per year are expended for water resources management, of which $3 billion per year are spent by the Federal Government and $9 to $12 billion by State, local, and regional agencies. Twenty percent of all the expenditures associated with municipalities in the United States is devoted to water resources problems. The responsibilities and areas of need on the part of Federal agencies are provided in ref. 4-2.

There has been substantial progress in demonstrating and applying remote-sensing observations for water resources management with use of the Landsat-1, Landsat-2, and NOAA VHRR systems, wherein the visible, near-IR, and thermal regions of the electromagnetic spectrum have been employed. The results show, for example, that the dynamics of snow cover, surface-water area (including postflood, inundated areas), and land-use or surface-cover themes relevant to hydrology can be delineated and used for water management and prediction purposes.

There are some important and fundamental parameters that are not amenable to direct sampling by visible, near-IR, and thermal-IR systems. They do appear amenable to microwave sampling in that microwave radiation will penetrate the materials involved (soil or snow) and is quite sensitive to changes in the dielectric properties caused primarily by variations in water content. In addition, it is known that microwave radiation, under properly chosen conditions, can penetrate clouds and modest amounts of vegetation. Furthermore, it is quite clear that active microwave approaches provide a mechanism by which to obtain high spatial resolutions compatible with requirements for monitoring flooded areas, drainage basin characteristics, and soil moisture variations over small watersheds or fields.

Within the water resources area, there are several application areas that must be given priority, as follows.

1. Soil moisture monitoring to help specify water balance and runoff potential on watersheds.

2. Snowpack moisture equivalent and liquid-water monitoring to specify water available for runoff. This application is particularly important in the western United States, where snowpack yield provides the water for most hydroelectric power generation, irrigation, some flooding, and recreation.

3. Quantitative specification of runoff coefficients on small watersheds; the integrated effects of land use/surface cover, soil permeability and type, and surface cover must be specified - together with other efforts to delineate stream pattern, stream density, stream lengths and widths, and basin area - to make estimates of watershed yield.

4. Delineation of freeze/thaw lines in many areas, particularly in the spring months on the northern Great Plains, where this condition markedly affects the magnitude and character of runoff.

For the aforementioned application areas, the major investigation objectives and activities that must be considered in developing a microwave observational capability are as follows.

1. Information content - The first step in deducing the applicability of remote-sensing observations is to ascertain what information resides within these observations, to what accuracy the information can be specified, and the observational needs of the hydrologic community in order to exceed the capability provided by conventional observational systems.

2. Watershed runoff/water balance/water resources systems models - For the great majority of water resources management agencies, models represent the major management, decisionmaking tool. Therefore, to demonstrate applicability, it must be shown that remote-sensing data can be used in models of the aforementioned type. These models may range from the empirical, simple watershed runoff models of the "rational formula" type, where a coefficient is involved, to the numerical, continuous simulation parametric models of the type represented by the Stanford IV or USACE SSARR[5] models. In any case, it should be demonstrated that these models can utilize the remote-sensing data to produce comparable or more accurate results than can be presently derived and that the input data can be acquired faster and at less cost.

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[5]Streamflow synthesis and reservoir regulations.

3. ASVT - The final step before operational utilization of remotely sensed data is its evaluation in a quasi-operational framework. Within the NASA framework, the data would be evaluated in an ASVT environment. The same procedure needs to be followed in developing and demonstrating a microwave observational capability. In the following subsections, the time periods in which these tests should occur are specified.

Considerable effort has already been devoted to assessing the applicability of active microwave systems for application areas in water resources (refs. 4-1 and 4-5). Some of this work is summarized in table 4-4; indications of progress are provided, as well as observational requirements and the relationship to other systems such as passive microwave systems and visible/IR sensors. Table 4-5 contains a quantification of the current status of knowledge of the active microwave response to specific parameters pertaining to each of five water resources applications. The approach utilizes the progressive steps toward spaceborne system implementation by starting with theory and laboratory work and progressing toward that ultimate goal with the use of ground-based and aircraft systems.

These tables generally indicate that, in all areas, substantial work is still needed; but the most progress and usable/referenceable knowledge exist in the case of surface-water mapping, followed by soil moisture and, then, freeze/thaw lines and snowpack monitoring. For all areas, the flight of an active microwave SAR in space is being awaited. The first opportunity to see such data will come with the launch of Seasat-A in 1978.

Approach

Soil moisture monitoring.- The purpose of this activity is to monitor soil moisture variations under bare and vegetated conditions. Soil moisture content is a fundamental parameter in water resources applications, including crop yield prediction, flood forecasting, runoff prediction for assessing watershed yield and planning, reservoir management, and a variety of other agricultural, hydrological, and meteorological applications. Although it has been experimentally demonstrated that the radar response is very sensitive to soil moisture content, a quantitative determination of moisture content requires a thorough understanding of the dependence of the radar response on interference factors such as surface roughness and vegetation cover. Research to date indicates that the effect of surface roughness can be minimized by operating in the 4- to 5-GHz frequency range at nadir angles in the 7° to 17° range (ref. 4-12). The sensitivity of radar to moisture in the soil underlying a vegetation canopy has also been investigated for a few economically important crops such as wheat, corn, milo, soybeans, and others. Preliminary results of this ongoing research effort at the University of Kansas indicate that algorithms for predicting soil moisture content of vegetated terrain will probably require the use of a two-frequency radar system.

TABLE 4-4.- WATER RESOURCES APPLICATIONS SYSTEMS REQUIREMENTS

Application	Role[a]: Active microwave	Role[a]: Passive microwave	Role[a]: Visible/IR	Wave-length, cm	Interpretation resolution, m: Desire	Interpretation resolution, m: Accept	Nadir angle, deg	Polar-ization type	Revisit interval	Status[b]	Priority and feasibility[c]	Comments
Soil moisture monitoring												Unique capability
Cultivated areas	P	P	S	6 to 8 and 1.7 to 2.2	30	90	7 to 17	HH and cross	1 to 7 days	SE	VH	
Uncultivated areas	P	P	S	2 to 30 MF[d]	30	90	7 to 17	HH and cross	1 to 7 days	SE	VH	
Snowfield (equivalent moisture and liquid water) mapping	P	C	C	1 to 30 MF[d]	30	90	CS[e]	CS[e]	3 to 15 days	UT	VH	Limited experimentation to date
Watershed												Unique capability Proven capability
Runoff coefficient estimate	P	P	S	3 to 30 MF[d]	30	90	CS[e]	CS[e]	Seasonal	SE	H	
Drainage pattern	P	N	C	3 to 30 MF[d]	30	90	CS[e]	CS[e]	Annual	PS	L	
Land-use mapping	P	N	C	3 to 30 MF[d]	30	90	CS[e]	CS[e]	Annual	SE	L	
Surface-water, flood, and wetland mapping	P	N	C	Any	10	30	Any	Any	Event determined	PC/SE	M	Operational capability
Freeze/thaw line monitoring	P	C	S	3 to 30 MF[d]	90	200	CS[e]	CS[e]	3 to 15 days	UT	M	Limited experimentation to date

[a]The role symbols are defined as follows.
- P - prime sensor
- C - complementary sensor
- S - supportive sensor
- N - not needed

[b]The status symbols are defined as follows.
- PC - proven capability
- SE - strong evidence of capability
- PS - potential suggested by experimentation
- UT - under test

[c]The priority and feasibility symbols are defined as follows.
- VH - very high priority and feasibility
- H - high priority and feasibility
- M - medium priority and feasibility
- L - low priority and feasibility

[d]MF - multifrequency.

[e]CS - cannot be specified at this time.

TABLE 4-5.- STATUS OF ACTIVE MICROWAVE PROGRAM IN WATER RESOURCES APPLICATIONS[a]

(a) Soil moisture monitoring

Variable	Theoretical modeling and laboratory experiments			Ground-based experiments			Aircraft experiments			Spacecraft experiments		
	Cover			Cover			Cover			Cover		
	Bare	Vegetation	Snow	Bare	Vegetation	Snow	Bare	Vegetation	Snow	Bare	Vegetation	Snow
Surface moisture content	2	2	1	3	2	1	1	1	1	1	1	--
Moisture profile	2	2	1	3	2	1	--	--	--	--	--	--
Surface roughness	3	2	--	3	2	--	1	1	--	--	--	--
Salinity	2	2	--	--	--	--	--	--	--	--	--	--
Surface slope	2	2	--	3	2	--	2	2	--	--	--	--
Soil type	3	3	2	1	1	--	--	--	--	--	--	--
Freeze/thaw state	2	2	1	1	1	1	1	--	--	--	--	--
Vegetation type	N	2	--	N	2	--	N	2	--	--	--	--
Vegetation density	N	2	--	N	2	--	N	1	--	--	--	--
Vegetation moisture	N	2	--	N	2	--	N	1	--	--	--	--
Vegetation row effect	N	2	--	N	2	--	N	2	--	--	--	--
Diurnal cycle	N	1	--	N	2	1	N	--	--	--	--	--
Snow cover	1	--	1	N	--	1	--	--	1	--	--	--
Soil dielectric properties	3	N	N	N	N	N	N	N	N	N	N	N
Vegetation dielectric properties	N	1	N	N	N	N	N	N	N	N	N	N
Snow dielectric properties	N	N	2	N	N	N	N	N	N	N	N	N

(b) Snowfield (equivalent moisture) mapping

Variable	Theoretical modeling and laboratory experiments	Ground-based experiments	Aircraft experiments	Spacecraft experiments
Snow depth	3	1	--	--
Snow density	3	1	--	--
Snow temperature	1	1	--	--
Snow layering	1	--	--	--
Surface roughness	1	--	--	--
Snow wetness	1	1	--	--
Crystal structure (age parameter)	--	--	--	--
Diurnal cycle	--	1	--	--
Snow dielectric properties	3	1	N	N

[a]Table symbols are defined as follows.
N = not applicable
-- = no data acquired to date
1 = <35 percent of needed data acquired to date
2 = 35 to 65 percent of needed data acquired to date
3 = >65 percent but <100 percent of needed data acquired to date
+ = data collection complete

TABLE 4-5.- Concluded[b]

(c) Watershed runoff coefficient estimation and mapping of drainage basin characteristics

Variable	Theoretical modeling and laboratory experiments	Ground-based experiments	Aircraft experiments	Spacecraft experiments
Watershed size	N	N	1	--
Drainage density	N	N	+	--
Stream length	N	N	+	--
Stream width	N	N	+	--
Slope	N	N	1	--
Land use	N	N	2	--
Sinuosity	N	N	3	--
Permeability	N	N	--	--

(d) Surface-water and flood mapping

Variable	Theoretical modeling and laboratory experiments	Ground-based experiments	Aircraft experiments	Spacecraft experiments
Area	+	3	3	--
Area extent of vegetation cover	+	3	3	--
Vegetation density	N	--	1	--

(e) Freeze/thaw line monitoring

Variable	Theoretical modeling and laboratory experiments	Ground-based experiments	Aircraft experiments	Spacecraft experiments
Bare	+	1	--	--
Vegetated cover	1	1	--	--
Snow cover	1	1	--	--

[b]Table symbols are defined as follows.

N = not applicable
-- = no data acquired to date
1 = <35 percent of needed data acquired to date
2 = 35 to 65 percent of needed data acquired to date
3 = >65 percent but <100 percent of needed data acquired to date
+ = data collection complete

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Theoretical modeling and laboratory experiments.

a. Dielectric properties of soils should be measured as a function of moisture content, salinity, and temperature over the 1- to 8-GHz region. The data should be used to develop appropriate dielectric-mixing formulas.

b. Backscatter and emission models (based on experimental data) should be developed that incorporate the effects of soil moisture content and vegetation cover parameters.

c. Backscatter and emission models (based on experimental data) should be developed that incorporate the effects of soil moisture content for unfrozen ground with snow cover and frozen ground with and without snow cover.

2. Task B - Ground-based experiments.

a. Vegetation attenuation - If data on the attenuation by vegetation canopies are available, algorithms can be constructed to improve the accuracy of the soil moisture estimate provided by microwave sensors. To date, very few experiments have been conducted to acquire such data. Hence, it is recommended that a transmission system approach be used to measure the attenuation of each of several types of vegetation canopies as a function of frequency (1 to 8 GHz), nadir angle (0° to 30°), vegetation parameters (crop type, height, plant moisture content, density, row direction, etc.), and time of day.

(1) Sensor - A 1- to 8-GHz ground-based radar.

(2) Test site - Any agricultural test site.

(3) Frequency of data acquisition - Once every 7 to 10 days during the growing cycle.

(4) Interpretation technique development - Attenuation data should be integrated into radar soil moisture estimation models to improve accuracy of the estimate.

b. Simultaneous active/passive microwave measurements - Although a passive microwave radiometer is not yet capable of producing high-resolution imagery from space platforms, its demonstrated sensitivity to soil moisture content may potentially be used to "calibrate" the high-spatial-resolution soil moisture estimate provided by radar. A ground-based experiment with a combination of passive and active microwave sensors should be conducted to determine the improvement in the soil moisture estimate provided by the combined sensors over that provided by radar alone. The experiment should include both bare and vegetation-covered conditions.

(1) Sensors - C-band ground-based scatterometer and L-band or C-band radiometer.

(2) Needed sensor development - None, if the University of Kansas active system is used and the JSC or GSFC L-band radiometer system is used to acquire data simultaneously with the active microwave sensor.

(3) Test site - Any agricultural test site.

(4) Interpretive technique development - Algorithms should be developed for utilizing the combination of active and passive microwave data for predicting soil moisture content.

3. Task C - Aircraft experiments. The soil-moisture-mapping capability attributable to active microwave remote sensing should be evaluated for a variety of cultivated and uncultivated test sites through repetitive coverage simulating periodic coverage by a satellite system. Because the microwave sensors respond only to the moisture content in the top few centimeters of the soil, a water-balance model should be developed to incorporate the multidate data provided by the microwave sensors to predict the moisture content at the deeper layers. In addition to airborne sensors, ground-based sensors should also be used to calibrate the airborne sensors and to monitor the moisture content of selected fields on a daily basis so that an accurate evaluation of the needed frequency of coverage of a satellite system can be made.

a. Sensors -

(1) Airborne sensors - L-band, C-band, and Ku-band NASA/JSC scatterometers and imagers as availability and resources permit, plus the NASA/JSC MFMR.

(2) Ground sensors - Ground-based radar spectrometer.

b. Coverage requirements - Every 9 days during the growing season.

c. Test sites -

(1) FY 1977 to 1979 - Finney County, Kansas, LACIE test site.

(2) FY 1978 to 1980 - To be determined; possible candidates include the Washita River test site near Chickasha, Oklahoma, and the Kern River test site in southern California.

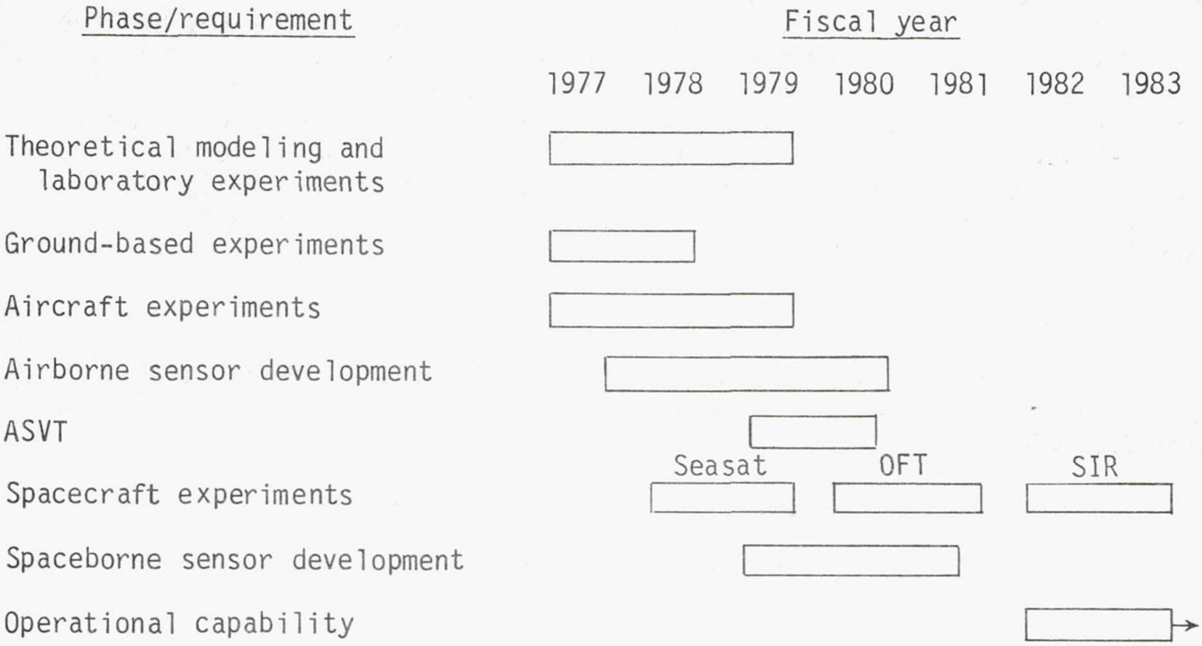
d. Needed sensor development - C-band imager, 5° to 20° nadir angle range, 12.5-m single-look resolution, and HH- and cross-polarization capability.

e. Interpretation techniques development - An appropriate water-balance model for bare and vegetated terrain should be developed that uses radar data and weather station information as inputs and yields an estimate-of-soil-moisture profile down to 50 cm as output.

f. Ground-truth support - Soil moisture content profile and vegetation cover parameters (crop type, density, row direction and spacing, plant moisture, etc.).

4. Task D - Spacecraft experiments. The first opportunity to evaluate the potential of active microwave remote sensing in soil moisture determination will be provided by the Seasat L-band SAR. Although experimental evidence to date indicates that C-band is superior to L-band for mapping soil moisture content, the Seasat L-band SAR should certainly provide results superior to what can be obtained with optical and thermal-IR sensors. Other opportunities include the Shuttle OFT flights and the projected 1982 or 1983 flight of the SIR. Detailed experiment specifications (test sites, exact sensor parameters, ground truth, etc.) will have to be deferred until extensive testing from airborne platforms has been conducted.

The scheduling relevant to these tasks is as follows.



	1977	1978	1979	1980	1981	1982	1983
Resources requirements (see footnote 4 on p. 137), thousands of dollars	300	550	350	350	300	300	300

Snowfield mapping.- Snowpacks provide most of the water supply in the western United States. The water runoff from high elevations also provides a major portion of the electrical energy. Knowledge of the depth, density, extent, and wetness of snowpacks on a timely basis permits optimum management of water reservoirs, allocation of water resources, scheduling of hydroelectric power, and irrigation planning. Sudden thaws of the snow can cause extensive flooding resulting in loss of lives and property. Such hazards can be reduced or eliminated if snowpack conditions are known with an adequate lead time.

Snow course measurements presently provide information regarding how much water equivalent exists at the time on the basis of statistical inference. Automated measurements by "snow pillows" or by the Smith density profile technique can furnish significant additional information. The SCS is installing a network of approximately 400 pressure pillows for remote, automatic acquisition of snow mass data (termed "water equivalent") in its "Sno-Tel" system.

At the present time, little information is available regarding the time and rate of release of melt water from the snowpack. Also, the water storage capacity of snowpacks for rainfall is not known.

Information about the snowpack evidently can be improved and would be valuable if it were available on a timely basis. Satellite-borne active microwave sensors have the potential to provide synoptic, repetitive information regarding snowpack extent, depth, density, and wetness.

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Theoretical modeling and laboratory experiments.

a. Extensive measurements should be conducted to determine the dependence of the dielectric properties of snow on wetness, density, average grain size, crystal structure, and microwave frequency (1 to 18 GHz and 35 GHz).

b. Backscatter and emission models (based on experimental data) should be developed that incorporate the effects of snow parameters (wetness, temperature and density profiles, depth, grain size, and crystal structure) as a function of the sensor parameters (frequency, polarization, and nadir angle).

2. Task B - Ground-based experiments. Knowledge of microwave response to snow moisture and wetness is limited, although significant and important knowledge indicating a potential for water resources management has been gained. It is recommended that an extensive measurement program be conducted to determine the backscatter and radiative emission response to snow as a function of the snow parameters (wetness, density and temperature profiles, depth, density, grain size, and crystalline structure) and the sensor parameters (frequency, polarization, and nadir angle). Although radar is the primary sensor of interest in ongoing experiments, passive microwave radiometers should also be included whenever it is feasible.

a. Sensors - A truck-mounted radar spectrometer plus available passive microwave radiometers.

b. Test sites -

(1) FY 1977 to 1978 - The CSSL's test site.

(2) FY 1978 to 1979 - Test site to be chosen in Colorado. Steamboat Springs test site is a likely candidate. Experiment can be

conducted in cooperation with NOAA (Boulder, Colorado), USFS, SCS, Institute for Alpine Research, and USGS.

c. Ground-truth support - Snow wetness, density and temperature profiles, snow depth, grain size, and crystalline structure. Two approaches are recommended for measuring snow wetness: (1) freezing calorimeter technique and (2) the microwave transmission technique developed by Linlor (NASA/Ames Research Center).

3. Task C - Aircraft experiments. An aircraft program should be instituted to acquire microwave data supported by ground-truth data over selected sites. Starting with the Steamboat Springs, Colorado, test site in 1978, the program can be gradually broadened to include other sites involving other types of snow as success and insight are gained from the results of the ground-based experiments.

a. Sensors - L-band, C-band, and Ku-band NASA/JSC scatterometers and the MFMR system.

b. Coverage requirements - Four flights during the winter season.

c. Test sites -

(1) FY 1978 to 1980 - Steamboat Springs, Colorado.

(2) FY 1979 to 1982 - Test sites with different snow types (Minnesota, Sierra Nevada Range, Cascade Range, Alaska, etc.).

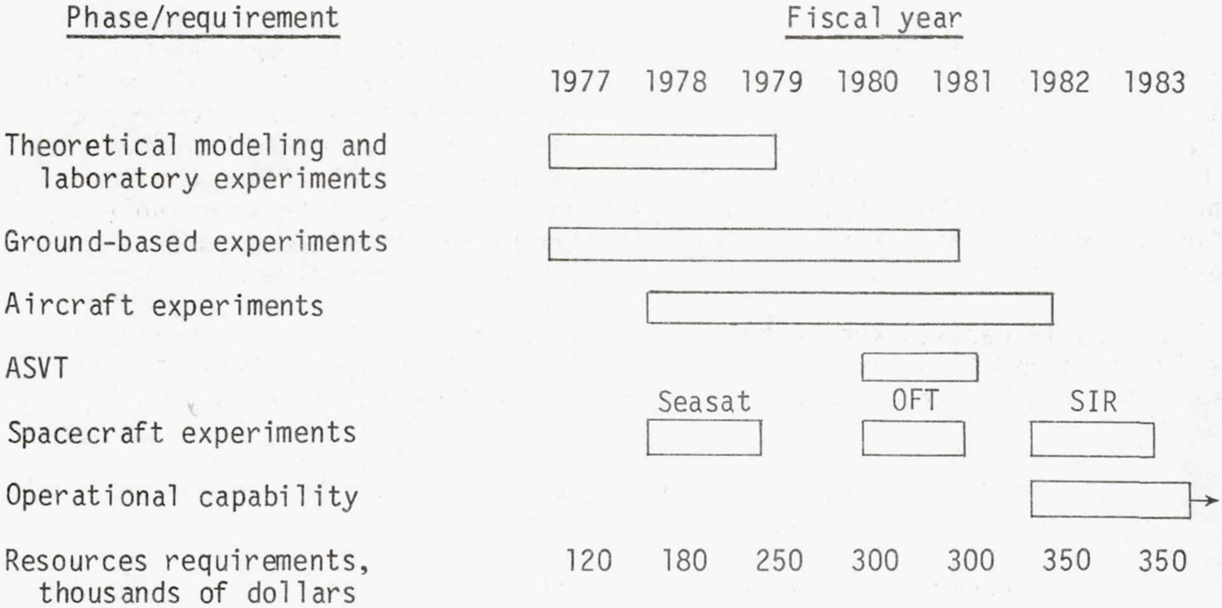
d. Needed sensor development - Unknown at this time; specification of optimum sensor parameters for snow mapping will depend on the results of ground-based experiments.

e. Interpretation techniques development - Algorithms should be developed that utilize active (and passive) microwave data to estimate snowpack/runoff.

f. Ground-truth support - Similar to that for ground-based experiments.

4. Task D - Spacecraft experiments. Seasat, with its L-band SAR, will provide the first opportunity for evaluating the potential of active microwave sensing of snow. An operational system will probably require a two-frequency SAR - e.g., one frequency around the L-band and a higher frequency in the Ku- or Ka-band. Such an opportunity will come with the projected 1982 to 1983 flight of the SIR.

The scheduling relevant to these tasks is as follows.



<u>Watershed runoff coefficient estimation and mapping of drainage basin characteristics</u>.- The general purpose for this area of endeavor is to predict runoff potential for ungaged, medium-sized watersheds ranging in size from 2 to 1000 km^2 in projected surface area. Storm runoff is related to the amount of storage available in or near the surface, occurring in the form of interception, storage, and infiltration. The yield of watershed is related to basin site, stream length and density, and other factors because the drainage basin evolves in such a way as to achieve a balanced throughput capability as a function of the climate and the magnitude of the input variables (precipitation).

Runoff coefficient quantification: Active microwave systems of appropriate wavelengths are thought to be sensitive to soil particle size, vegetation, roughness, and scene moisture. At this time, these factors are reflected in the choice of runoff coefficient determined subjectively by an experienced hydrologist working on a given watershed. This coefficient is provided in an equation of the type utilized by the SCS (see ref. 4-1).

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Theoretical modeling and ground-based experiments. This task is, at the outset, an empirically oriented one. Therefore, theory and ground-based measurements are not suggested initially. After the feasibility and correlation of aircraft and spacecraft SAR observations with measured runoff coefficients are established, careful ground-based measurements should be made to establish the responsiveness of active microwave measurements to soil porosity or infiltration capacity and vegetation density to develop the capability to provide these parameters to more complex

models. Some or all of these tasks may be accomplished in agriculturally related tasks.

2. Task B - Aircraft experiments. The first phase in applying active microwave systems for specifying runoff coefficients was started with observations over small watersheds in Oklahoma, where data have been acquired by using the JPL L-band imaging system on the NASA Convair 990 and the ERIM SAR system. The preliminary results of this research indicate that high-runoff-potential watersheds can be objectively separated from low-runoff-potential watersheds. More work with scatterometer data is needed to understand and specify more clearly the validity of these results.

The early results should be tested over a variety of areas - first in the Oklahoma and Texas areas, with gradual movement to other distinctly different areas. Suggested other areas are small watersheds in Pennsylvania and Idaho.

a. Sensors - L-band, C-band, and Ku-band NASA/JSC scatterometers and imagers as availability and resources permit.

b. Frequency of coverage - Once per season.

c. Test sites -

(1) FY 1976 to 1978 - Selected watersheds in Texas and Oklahoma.

(2) FY 1977 to 1979 - Selected watersheds in Pennsylvania.

(3) FY 1978 to 1979 - Selected watersheds in Idaho.

d. Ground-truth support - The basic ground-based data that are needed for this effort consist of detailed rainfall and runoff data covering a long period of time so that correlations between measured runoff coefficients and microwave observations can be established. In addition, good information on land use, surface cover, and soil characteristics is needed. In the last instance, information on soil permeability and/or hydrologic conductivity is necessary. The total information set needed here is, in general, only available at experimental watershed sites such as those operated by USDA agency research centers. Whenever possible, these watersheds should be utilized in microwave runoff coefficient studies.

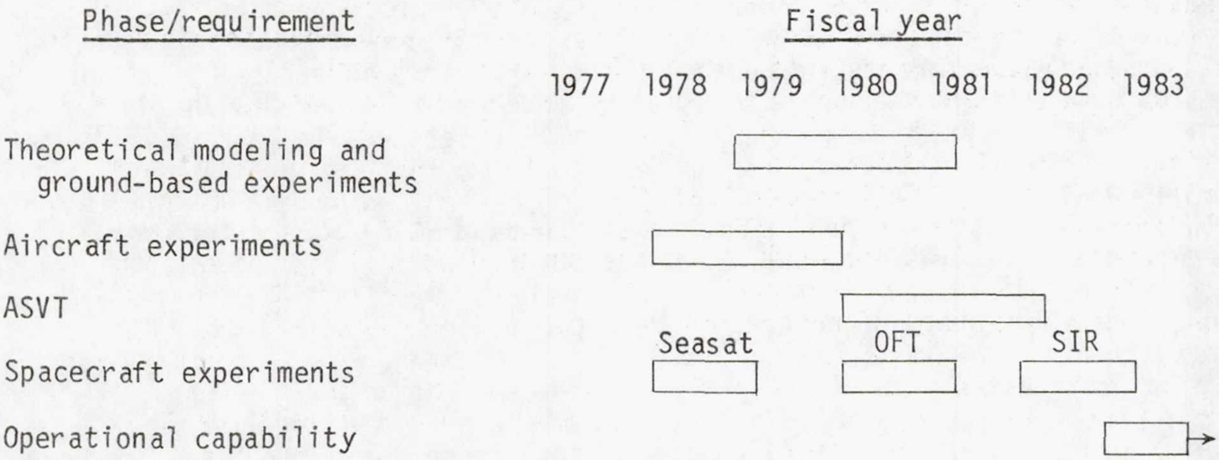
3. Task C - Spacecraft experiments. Every opportunity should be used to develop correlations between measured runoff coefficients and data from active microwave observations from space having appropriate spatial resolutions (<100 m). The first opportunity will come with Seasat, L-band SAR, which should be providing data in the 1978 to 1979 time frame. Other opportunities should follow with the Shuttle OFT flights and the projected 1982 to 1983 flight of the SIR.

a. FY 1978 to 1979 - Seasat SAR - observations and analysis.

b. FY 1980 to 1981 - Shuttle geology SAR (OFT-2) flights and possibly Technology Development Satellite/SAR (OFT-5) flights over Texas, Oklahoma, Maryland, and California.

c. FY 1982 to 1983 - Shuttle sortie SIR flights over areas noted previously.

The scheduling relevant to these tasks is as follows.



Resources requirements, thousands of dollars	1977	1978	1979	1980	1981	1982	1983
Aircraft experiments		50	50	50	50	50	50
Spacecraft experiments		25	75	50	50	25	75
Total		75	125	100	100	75	125

Drainage basin characteristics: The variation in drainage basin characteristics and land-use features can be used to provide indices of peak flows, minimum flows, and annual yields (measurements of stream length, drainage density, basin area, etc.) or to estimate the degree of imperviousness, information leading toward better estimates of flow rates and storm runoff volume in response to various storm inputs.

The feasibility of observing stream networks has already been established by McCoy (ref. 4-13) with the use of aircraft data. The role of active microwave data for land-use identification and basin feature mapping will largely be supportive of high-resolution spacecraft and aircraft observations in the visible/IR regions. The advantages of all-weather coverage are counterbalanced by the low frequency-of-coverage requirements. High spatial resolution can also be provided by these competitive systems. An evaluation of radar/microwave data, when combined with visible, near-IR, and thermal-IR observations, should be made to determine how much improvement in classification accuracy can be attained. The ability to penetrate modest amounts of vegetation and snow cover will be an advantage that should result in improved delineation of drainage basin features and land-use features.

At every opportunity, spacecraft observations should be evaluated to quantify the contribution to delineating the aforementioned features. As already noted, Seasat, Shuttle OFT flights, and Shuttle sortie flights are expected to carry sensors that will afford this opportunity.

Cost-benefit studies and user agency interaction: The contribution of microwave data to improving specification of runoff coefficients and drainage basin characteristics needs to be quantified in terms of cost effectiveness (savings in speed and costs for labor) and benefits (reduction in design costs). These factors must be specified in terms of their gain in contribution over and above contributions made by visible/IR systems.

Space systems and sensor requirements studies: Because aircraft measurements are performed with relatively high resolutions (10 to 25 m), care should be taken to allow the eventual degradation of the data to evaluate the results associated with various resolution factors and signal-to-noise ratios. This task should be performed in terms of specifying differences in runoff coefficients between watersheds, mapping drainage networks, and classifying land use. Furthermore, care should be taken to define requirements for frequency of coverage. In this case, the task should not be difficult because the requirements are apparently not very stringent.

Surface-water and flood mapping.- The capability of mapping surface-water bodies (ponds, lakes, etc.) is useful under the general framework of water resources management. Of particular interest is the ability to map flood-inundated areas under cloud cover conditions. Such a capability can be used for conducting relief efforts, assessing loss of life and property, and delineating the extent of the flood plain.

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Theoretical modeling and laboratory experiments. In the absence of vegetation, the discrimination of water and land surfaces is made on the basis of backscatter return differences due to the difference in surface roughness. In virtually all cases, water is a smoother, more homogeneous target giving a much lower return intensity. Theoretical models for rough-surface scattering are in good agreement with experimental evidence and indicate that discrimination may be easily performed over a wide range of frequencies, incident angles, and polarizations. No additional theoretical or laboratory work is required to support this application.

The presence of vegetation standing above a water surface develops into a distinctly different scattering problem. A volume scattering model that takes into account features standing above a perfectly conducting plane must now be considered. Some theoretical models exist that give some insight into this problem; however, additional work is needed. The complexity and size of the target make this problem unsuitable for detailed laboratory investigation other than definition of vegetation dielectric constant as a function of moisture content. Theoretical models should be developed on the basis of data generated by ground-based experiments.

2. Task B - Ground-based experiments. For flood and wetland mapping, it is desirable to detect surface standing water beneath vegetation cover that may range from a few centimeters of grass to approximately a 30-m height of trees.

Ground-based experiments are extremely desirable for vegetation height and sizes compatible with the elevation and resolution cell size of practical ground-based systems. A ground-based program for the measurement of grass and sedges in a coastal marsh is needed. The extension to greater vegetation heights and a wider variety of environment must be performed initially with an airborne sensor.

The data needed for the vegetated test sites are those of backscattering cross section over a frequency range of 1 to 35 GHz, an incident angle range of 0^{o} to 60^{o}, and a full polarization complement.

a. Sensor - Truck-mounted radar spectrometer.

b. Test sites - Two basic test sites are required, one in a coastal wetland environment and another is an inland freshwater environment. In both cases, the vegetation cover should span as many types and species as possible in a restricted region and under a height limitation on the order of 1 m (a few feet). The following sites are suggested.

(1) Atchafalaya Floodway in Louisiana - This region has served as a coastal marsh test site, and extensive prior data are available for the region.

(2) Freshwater test site - The location of this site is not critical and is not specified. The primary criterion for selection of this site should be proximity to the site location of the measurement facility.

3. Task C - Aircraft experiments. The test sites established for the ground-based measurement program should be used here as well. An additional freshwater wetland area should be included. This additional coverage could best be achieved by moving inland in the Atchafalaya region. Another possible alternative is establishment of a separate freshwater wetland site along the Mississippi River.

To test the capabilities of radar to provide data for mapping flooded areas, missions should be flown over targets of opportunity in storm situations, above the cloud cover.

a. Sensors - Available imaging systems such as JPL's X-band and L-band SAR's or JSC's X-band imager.

b. Coverage requirements -

(1) Wetland mapping - No specific requirements.

(2) Flood situations - As soon as the flooding occurs.

c. Test sites -

(1) Wetland mapping - Same as noted previously.

(2) Flood situations - Flooded areas.

(3) Rice croplands - Early season bare-water scenes.

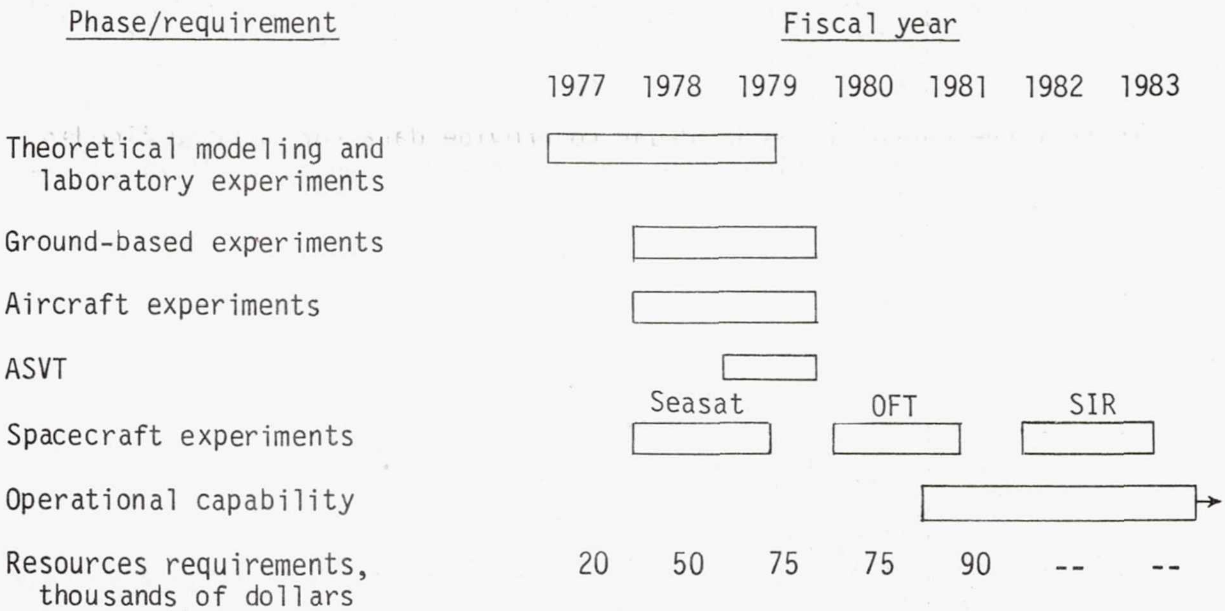
d. Interpretation techniques development - Resolution requirements should be established for conducting wet lake/playa census, dam inventory, and reservoir status monitoring.

e. Ground-truth support - Simultaneous ground-truth support must be provided in conjunction with each aircraft mission. For the water, only two basic measurements are required. First, the areal extent of water that may be masked by vegetation cover must be defined. Second, in the coastal environment, the salinity of the water must be measured. The bulk of ground truth will involve sampling of the vegetation to include type, height, density, and moisture content. The delineation of vegetation type will not normally change over the test interval and will require only periodic updating. However, the height, density, and moisture content measurements must be concurrent with the aircraft overflights.

4. Task D - Spacecraft experiments. The test sites established for the aircraft program should be maintained for initial spacecraft verification experiments with Seasat. With the additional coverage available with the Shuttle system, at least one additional wetland test site should be established in a tropical environment.

Active microwave imagery acquired by satellite systems over flooded areas should be interpreted by using data-processing algorithms to determine the operational utility of radar in flood relief operations.

The scheduling relevant to these tasks is as follows.



Freeze/thaw line monitoring.- There is considerable interest in defining areas on the ground that are frozen (either temporarily or permanently) so that special precautions can be taken to accommodate rapid change of environmental conditions. These changes could be in the form of rapid runoff of melted snow into reservoir areas, extreme ground motion caused by freeze/thaw cycles, changes in trafficability conditions for cross-country mobility, etc. If environmental changes are slow, there are generally precautions that have been established to control the large forces involved. Even when these environmental changes caused by freeze/thaw cycles take place over short time intervals, procedures can be followed to minimize damage or loss of resources if a warning or monitoring system can be devised.

One such monitoring system that appears to have a high potential for success is an active microwave sensor system. These systems are well qualified for freeze/thaw monitoring because (1) they can be used to produce images of large areas quickly and accurately, (2) microwaves are sensitive to the large change in electrical properties of the ground when the ground changes state in the freeze/thaw cycle, and (3) microwaves (at certain frequencies) can penetrate surface materials (i.e., snow, vegetation, and - to a certain extent - unfrozen surface soil) to detect a frozen material interface.

The basic application areas for monitoring freeze/thaw lines are in mapping the permanently frozen areas (permafrost zones), mapping frozen surface materials for runoff calculation in hydrologic studies, and mapping frozen surface materials for agricultural use.

For the aforementioned application areas to be effectively addressed, two scientific objectives must be achieved through microwave measurements: (1) definition of the bounded area defined by surface and/or subsurface frozen material and (2) determination of the depth to the frozen boundaries. These scientific objectives are by no means trivial, because the definitions of areal extent and depth of frozen material are not clear even when ground measurements are taken. A predominantly frozen area can include smaller packets of unfrozen materials at various times during a diurnal cycle. Similarly, repeated freeze/thaw cycles can produce multiple layers of frozen and thawed material as a function of depth.

Fortunately, extremely accurate results are not required for most of the freeze/thaw applications. A microwave sensor with 90- to 200-m spatial resolution would generally give acceptable results. Even depth resolution is not extremely critical. Knowledge of the presence of frozen material, coupled with information relating short-time thermal history of the area, may provide enough information in many cases. Under extremely critical user requirements, crude estimates of the frozen layer thickness are adequate.

Once the state of the ground is known, as well as an estimate of freeze depth, the freeze/thaw line can be updated by using thermal-balance models and weather records. Corrections to model predictions can be made as measurement updates are obtained (every 3 to 15 days).

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Theoretical modeling and laboratory experiments.

a. Laboratory measurements of the dielectric properties of soils as a function of temperature, soil type, and moisture content have been conducted by Hoekstra and Delaney (ref. 4-14). Additional experiments should be conducted to determine the effect of layering.

b. Theoretical backscatter models should be developed (on the basis of ground-based and aircraft data) to improve the choice of sensor parameters for delineating freeze/thaw boundaries under bare and vegetated conditions.

2. Task B - Ground-based experiments. The theoretical relationships used in the identification of the freeze/thaw line are concerned with a decrease in reflectivity for the ground as the ground material changes from the thawed state to the frozen state. The change in reflectivity is due to the change in electrical properties at freezing temperatures. Recent measurements of the radar backscattering coefficient across the 1- to 8-GHz band (ref. 4-15) indicate a strong sensitivity to frozen/unfrozen soil conditions. It is planned to continue this investigation over the 1- to 18-GHz spectral range in conjunction with passive microwave measurements. Because of the nature of this application, the ground-based measurement portion can be conducted jointly with the snowfield-mapping application (see "Snowfield Mapping" subsection).

3. Task C - Aircraft experiments. Airborne experiments should be conducted for a variety of surface conditions on temporarily frozen ground and permafrost. Tests should be conducted during a freeze/thaw cycle so that the change in properties can be monitored. Because the freeze/thaw line detection depends on the identification of reflectance change, standard interpretation and data-processing techniques can be used. All such experiments should be supported with ground-truth surveys to document freeze/thaw conditions during airborne tests.

a. Sensors - L-band, C-band, and Ku-band NASA/JSC scatterometers and the MFMR system.

b. Coverage requirements - Several flights during the spring freeze/thaw cycles. Also, some of the experiments should include several flights during the 24-hour diurnal cycle.

c. Test sites -

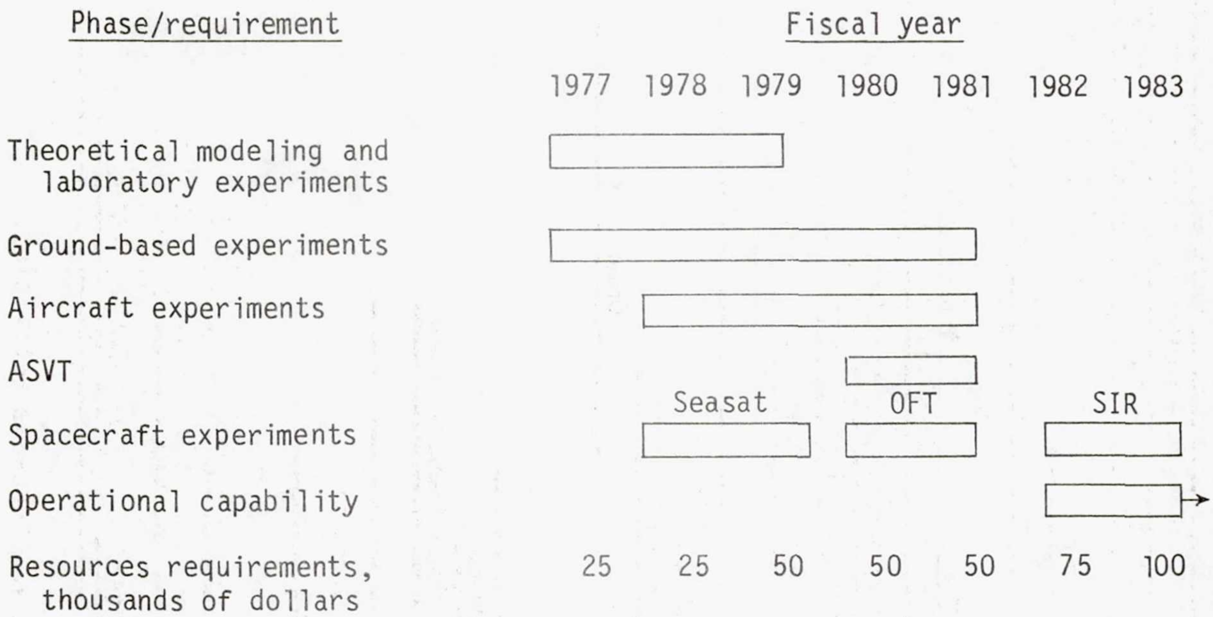
(1) FY 1978 to 1980 - Steamboat Springs, Colorado, test site.

(2) FY 1979 to 1982 - To be selected.

4. Task D - Spacecraft experiments. The first opportunity to evaluate the capabilities of active microwave sensors in delineating freeze/thaw boundaries will be provided by the Seasat SAR system. Other opportunities will follow with the Shuttle OFT flight and the projected flight of the SIR

scheduled for 1982 to 1983. Studies should be conducted with Seasat imagery to evaluate resolution requirements for mapping freeze/thaw boundaries.

The scheduling relevant to these tasks is as follows.



Development Plan

Figure 4-4 is a water resources applications development plan, in flow chart format, summarizing the major steps between the present status of each application area and the ultimate goal - operational capability. The associated schedules of ground-based, aircraft, and spacecraft experiments for each of the major application areas are summarized in figure 4-5, the corresponding resource requirements are summarized in table 4-6, and the test site locations are indicated in figure 4-6.

Summary and Recommendations

The major application areas were rated with respect to priority and feasibility as follows.

<u>Very high</u>:

1. Soil moisture monitoring (including cultivated and uncultivated areas)

2. Snowpack moisture equivalent and wetness monitoring

<u>High</u>: Watershed runoff coefficient estimation

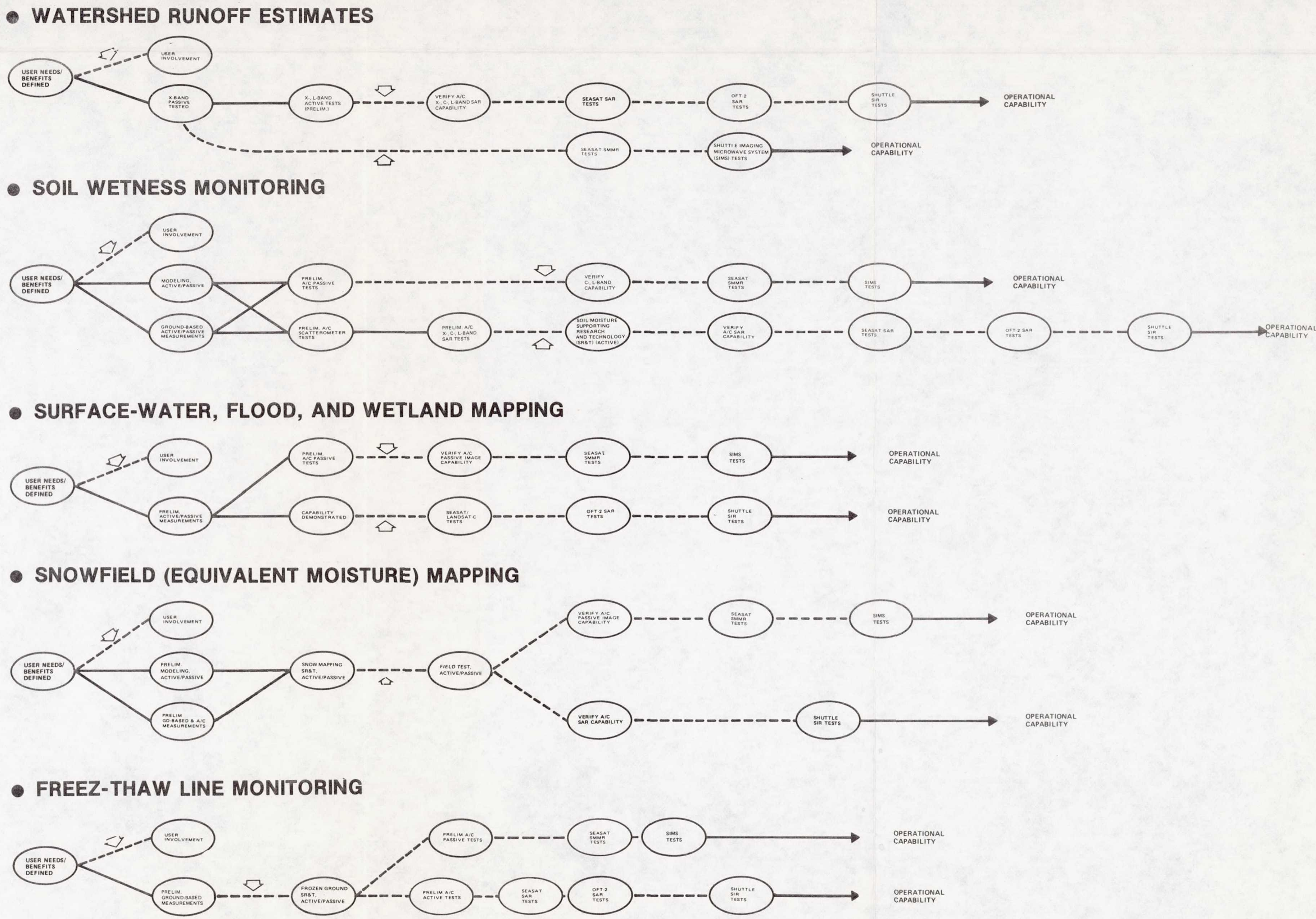


Figure 4-4.- Water resources development plan.

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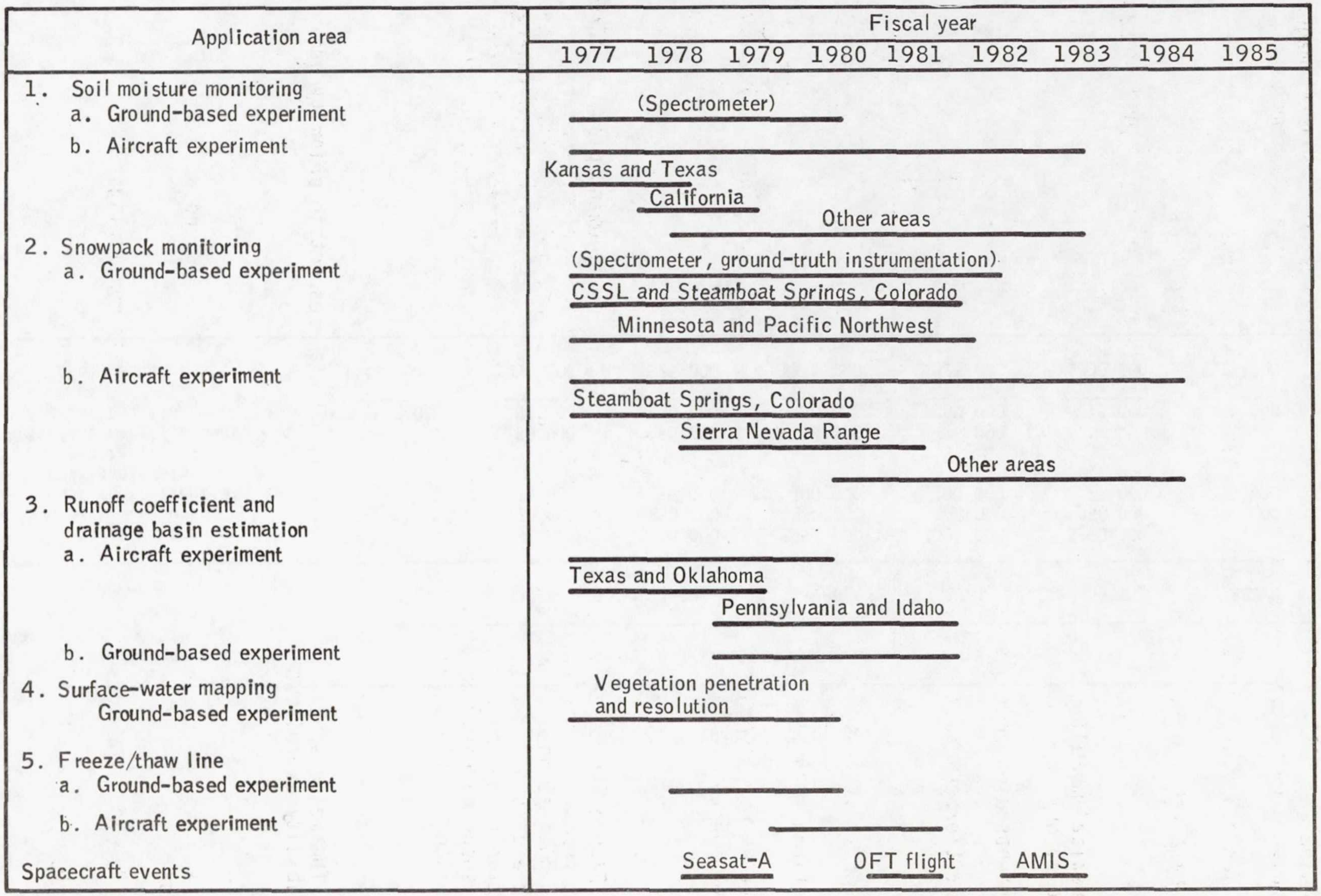

Figure 4-5.- Water resources/active microwave activities.

TABLE 4-6.- WATER RESOURCES FUNDING REQUIREMENTS

Application area	Fiscal year						
	1977	1978	1979	1980	1981	1982	1983
Soil moisture monitoring	$300 000	$550 000	$350 000	$350 000	$300 000	$300 000	--
Snowpack monitoring	120 000	180 000	250 000	300 000	300 000	350 000	$350 000
Runoff coefficient and drainage basin characteristics		75 000	125 000	100 000	100 000	75 000	125 000
Surface water, floods, etc.		20 000	50 000	75 000	75 000	--	--
Freeze/thaw line	25 000	25 000	50 000	50 000	50 000	75 000	100 000
Total resources	$445 000	$850 000	$825 000	$875 000	$825 000	$800 000	$575 000

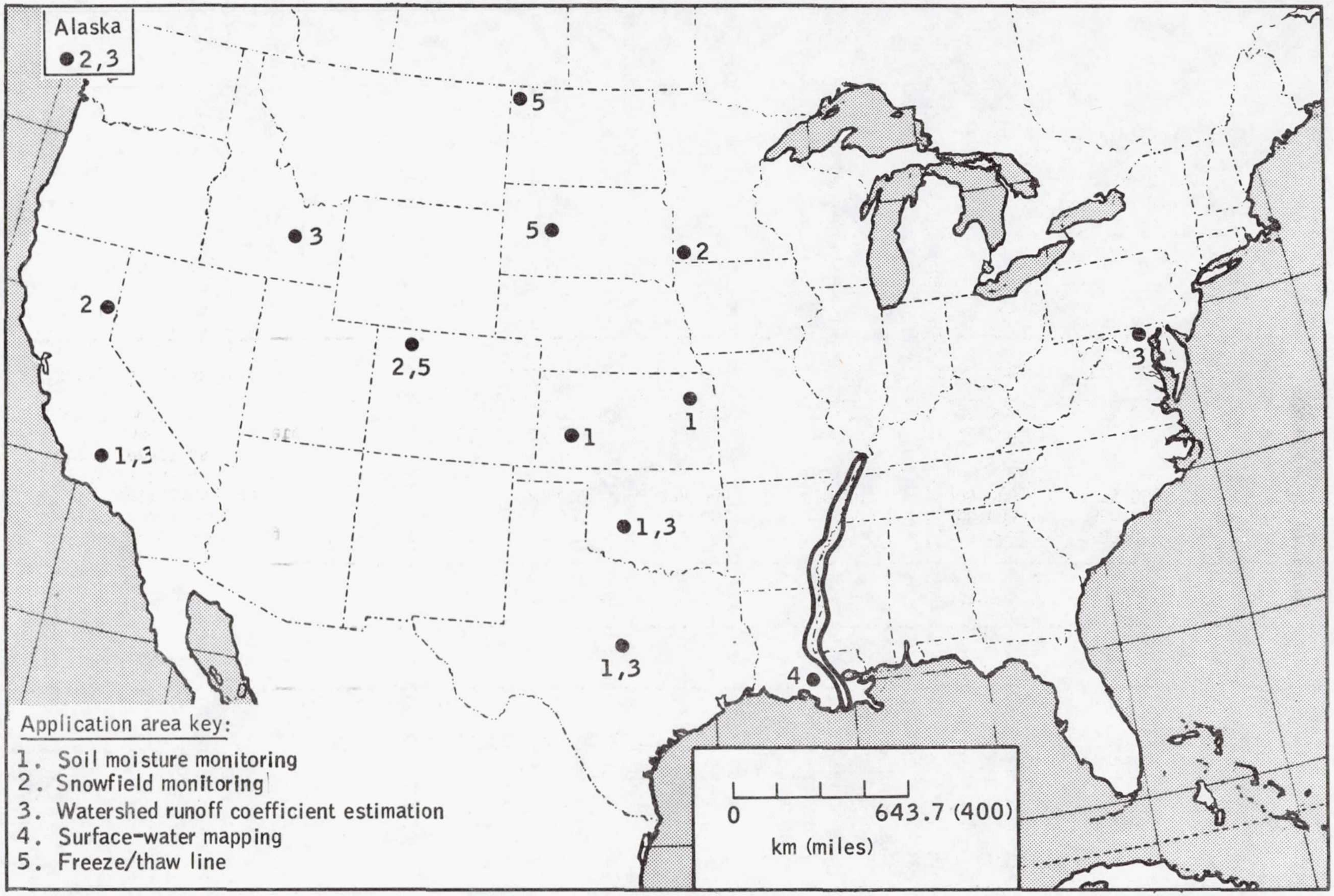

Figure 4-6.- Water resources applications test sites.

Medium:

1. Surface-water, flood, and wetland mapping

2. Freeze/thaw line monitoring

Low:

1. Drainage pattern mapping

2. Land-use mapping

The recommendations are as follows.

1. Develop an airborne SAR for soil moisture monitoring. On the basis of ground-based-measurement results, the system should be a calibrated instrument capable of operating in the 4- to 5-GHz band with a 7^{o} to 17^{o} nadir angle range (minimum).

2. Emphasize analysis of repetitive aircraft measurements and Seasat-A observations of soil moisture variations over Kansas, Oklahoma, and southern California test sites.

3. Emphasize ground-based and aircraft measurement of snow properties with the use of test sites in the central Sierra Nevada Mountains of California and the Rocky Mountains of Colorado.

4. Establish correlation between aircraft and spaceborne SAR observations and measured runoff coefficients with the use of Oklahoma, Texas, and Pennsylvania test sites.

5. Demonstrate, by using spacecraft SAR, the near all-weather capability of spaceborne SAR (e.g., Seasat SAR) to provide data for mapping surface-water variations, including flooding situations.

MINERAL RESOURCES AND GEOLOGIC APPLICATIONS PROGRAM PLAN

Introduction

In geological exploration, more so than in any other geoscience endeavor, radar imagery has been documented as a major source of information. Imaging radars utilized as reconnaissance exploration tools over a wide spectrum of terrains have contributed important data leading to exploration and discovery of a wide diversity of mineral products. As a reconnaissance tool, radar imagery, through the presentation of a synoptic view, enables the geologist to rapidly delimit areas of potential interest that warrant low-altitude aerial coverage and surface examination in order to determine the desirability of subsurface exploration. One major reason radar provides unique data is that the angle and direction of illumination can be controlled regardless of lighting or weather conditions, a capability thus facilitating maximum enhancement of the geological structures most commonly topographically expressed. Equally significant is the capability of SAR to "sense" in a portion of the electromagnetic spectrum to which the human eye is denied access.

Although the geologist has already used imaging radars in varying degrees for (1) mineral and petroleum exploration, (2) regional geologic mapping, (3) detailed geologic mapping, (4) nuclear plant, dam, and other construction site selection, and (5) ground-water exploration through identification of porosity- and permeability-controlling fracture patterns, the full potential of such systems is yet to be realized. In fact, there is not yet a full understanding of terrain-energy interaction with changes in system and target parameters. Without such an understanding, optimum utilization of SAR's will not be achieved. Thus, efforts must be directed toward the following tasks.

1. The development of a better understanding of the effect of variations in terrain and system parameter interactions as reflected in the return signal

2. A better definition of the role of radar in a total-remote-sensing program

3. A further demonstration of the suitability of radar for a wide range of geologic investigations

To achieve such an end, experiments have been defined and categorized both to demonstrate utilization (application) and to better define energy-target interaction (developmental). The highest priority in the developmental area was assigned to the use of polarization properties for definition of surface parameters. The highest priority in the application area has been given to problems associated with mineral and petroleum exploration. Required conditions for the proposed experiments are as follows.

1. High incident angles for topographic information

2. Multifrequency, multipolarization transmission and reception

3. Observations at two or more aspect angles

4. Observations during different seasons

Any study of system parameters and the effect of variations in system parameters with variation in terrain parameters, if accomplished through imaging from a satellite or aircraft platform, necessarily will depend on the analysis of imagery. As a result, although the objectives of this program are twofold, they are isolated only by definition.

The geologist is in a somewhat unique position, for unlike his counterpart in the natural sciences, his demand for data is generally on a one-time basis and the areal extent of his investigation, once defined, is relatively small. The problems of the geologist, in many instances, have been solved without regard to frequency and polarization for numerous areas throughout the world in need of a "first look" reconnaissance survey. Because of this well-established capability, radar rapidly evolved from a Government-financed research and developmental sensor to an industrially utilized operational sensor. This change unfortunately resulted in a deemphasis of evaluation of system-terrain parameter interaction and a failure to fully exploit radar's capabilities. Thus, radars must continue to be used as operational systems, with their capabilities demonstrated for providing geologic data other than that of a reconnaissance nature. At the same time, system and terrain parameter interactions must continue to be researched. Although ultimately the majority of geologically oriented problems may be solved with single or low-multiple coverage, repeated coverage will be necessary in the experimental stage to define optimum terrain, seasonal, and system parameters for any specific task in a wide variety of environments. Table 4-7 is a summary of systems requirements for five utilization areas in mineral resources and geologic applications.

The present status (table 4-8) of the five broad areas of utilization indicates the degree to which operational radars are being used today. The majority of radar surveys in recent years have been wholly or partially oriented toward the acquisition of geologic data. Well understood is the effect of depression angle (ref. 4-16) on the return signal. The lack of full understanding of the effect of frequency variations (refs. 4-17 to 4-19) and polarization effects (ref. 4-20), together with the utilization of only X-band single-polarization systems commercially, has limited the utilization of radars in some areas of geologic investigation and provided the user with a less-than-optimum product.

Approach

Mapping structural features.- To define lineament or other structural or terrain features not subject to short-term change, in several of the test sites, it is proposed to detect and map lineaments as well as other terrain features, particularly those that are not detected through sensing in the visible region of the spectrum. However, the objectives are not confined to mapping per se but are also designed to demonstrate the role of radar in a total-remote-sensing program. Although radar may stand alone as an all-weather, day or night sensor (refs. 4-21 and 4-22), its role in geologic investigations becomes further enhanced with the demonstration that unique data - data provided neither by the Landsat MSS nor by aerial camera - can be generated. Through controlled experiments with simultaneous acquisition of ground data, an explanation for the revelation of unique terrain information would also be developed; thus, the geoscientist would be presented with necessary information for mission planning to obtain optimum results in other terrains. Because of the identification of numerous terrain elements and, to a large degree, the lack of understanding of the cause of their revelation, it is most important that the cause of revelation - not just revelation alone - be documented. Although extensive research in the past has suggested the reason for the detection of such features in numerous and diverse areas (refs. 4-11 and 4-23), for the most part this documentation has been without the benefit of simultaneous ground-truth acquisition and comparison with simultaneously generated aerial photography or Landsat MSS imagery.

TABLE 4-7.- MINERAL RESOURCES AND GEOLOGIC APPLICATIONS SYSTEMS REQUIREMENTS

Application	Role[a]			Wave-length, cm	Interpretation resolution, m		Nadir angle, deg	Polar-ization type	Revisit interval	Status[b]	Priority[c]	Comments
	Active microwave	Passive microwave	Visible/ IR		Desire	Accept						
Mineral and petroleum exploration	P	N	P	0.8 to 25 MF[d]	15	30	Stereo (aspect angle and incident angle dependent)	HH or VV, cross	Seasonal (4 times/yr)	SE	H	Excellent experimental evidence
Regional geologic mapping	P	N	S	.8 to 25 MF[d]	25	50	40 to 70	HH or VV, cross	Seasonal	PC	H	Operational capability
Detailed geologic mapping	S	N	P	.8 to 25 MF[d]	3	15	40 to 70 (stereo)	HH or VV, cross	Seasonal	SE	M	Limited evidence
Civil works applications	P	N	P	.8 to 25 MF[d]	15	30	40 to 70 (stereo)	HH or VV, cross	Seasonal	PC	H	Excellent experimental evidence
Ground-water exploration	P	S	P	.8 to 25	25	30	40 to 70 (aspect angle dependent)	HH or VV, cross	Seasonal	PS	M	Limited experimentation to date - fracture pattern detection

[a]The role symbols are defined as follows.
P - prime sensor
C - complementary sensor
S - supportive sensor
N - not needed

[b]The status symbols are defined as follows.
PC - proven capability
SE - strong evidence of capability
PS - potential suggested by experimentation

[c]The priority symbols are defined as follows.
H - high priority and feasibility application
M - medium priority and feasibility application

[d]MF - multifrequency.

TABLE 4-8.- STATUS OF ACTIVE MICROWAVE PROGRAM IN MINERAL RESOURCES AND GEOLOGIC APPLICATIONS

Variable	No. of theoretical modeling and laboratory experiments	No. of ground-based experiments	No. of aircraft experiments	No. of spacecraft experiments
Mineral and petroleum exploration and regional geologic mapping				
Drainage pattern	(a)	(a)	2	--
Topography	(a)	(a)	2	--
Fracture pattern	(a)	--	2	--
Rock type	1	--	--	--
Soil/rock cover (size)	1	--	2	--
Soil/rock cover (composition)	1	--	--	--
Vegetation	(a)	2	2	--
Moisture content	1	2	1	--
Detailed geologic mapping				
Drainage pattern	(a)	(a)	2	--
Topography	(a)	(a)	2	--
Fracture pattern	(a)	--	2	--
Rock type	1	--	--	--
Soil/rock cover (size)	1	--	2	--
Soil/rock cover (composition)	1	--	--	--
Vegetation	(a)	2	2	--
Moisture content	1	2	1	--
Civil works applications				
Drainage pattern	(a)	(a)	2	--
Topography	(a)	(a)	2	--
Fracture pattern	(a)	--	2	--
Rock type	1	--	--	--
Soil/rock cover (size)	1	--	2	--
Soil/rock cover (composition)	1	--	--	--
Vegetation	(a)	2	2	--
Moisture content	1	2	1	--
Ground-water exploration				
Drainage pattern	(a)	--	2	--
Topography	(a)	(a)	2	--
Fracture pattern	(a)	--	2	--
Rock type	(a)	(a)	--	--
Soil/rock cover (size)	1	--	2	--
Soil/rock cover (composition)	(a)	(a)	(a)	--
Vegetation	(a)	2	2	--
Moisture content	1	2	1	--

[a]Not applicable.

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Aircraft and spacecraft experiments. The capability of the SLAR to provide mapping data has already been well documented; hence, the following experiments are designed to further demonstrate that capability (in areas of renewed interest - for petroleum exploration and for critical fault data for nuclear reactor site selection), as well as utilize the all-weather, day or night capability (in an area of high-percentage cloud cover for which few geologic data are available).

a. Mineral and petroleum exploration - central Arkansas.

(1) Objective - To demonstrate the utility of temporal multifrequency-polarization radar data for mineral and petroleum exploration in a heavily forested terrain.

(2) Approach -

(a) Initially, aircraft radar imagery will be acquired and analyzed. Definition of best available frequency and polarization or combinations will be achieved.

(b) Comparisons will be made with published and field-acquired data.

(c) Spacecraft data covering the same area will be analyzed and correlated with aircraft-acquired data to establish the feasibility of spacecraft imaging. Once this feasibility is defined, additional sites of similar terrain environment will be evaluated.

(3) Sensors - Multifrequency, multipolarized radar imagery is required; however, optimum parameters of the system are not defined (but will be determined) because only single-frequency systems have been used to any extent in geologic mapping.

(4) Test site - Central Arkansas (center geographic coordinates: 35°30' N., 93°30' W.).

(5) Frequency of coverage - Seasonal coverage is required initially but probably is not required following the determination of the "best" time for coverage.

(6) Season and time constraints - Probably one after initial acquisition and analysis of data.

b. Geologic analysis - Eastern Coastal Plain.

(1) Objective - To determine utility of radar for the interpretation of subtle geological structure in a relatively low relief environment as related to site selection of nuclear reactors.

(2) Approach -

(a) Use photo-geologic techniques with aircraft-acquired radar to detect subtle structural features from variations in forest canopy and soil moisture.

(b) Radar imagery will be compared to processed NASA photography, and image products will be analyzed by various geologists and Earth scientists.

(3) Sensors - Dual wavelength (2 cm and 25 cm) radar, low and high incident angle, and two-aspect-angle imagery analysis.

(4) Test sites - Two areas will be studied: (1) near Fredericksburg, Virginia, (center geographic coordinates are approximately 38° N., 78° W.) and (2) near Charleston, South Carolina (center geographic coordinates are approximately 33° N., 81° W.).

(5) Frequency of coverage - Not applicable following the determination of "best" season coverage.

(6) Season and time constraints - Data should be collected twice during the year, once in January or February and once during the summer.

c. Geomorphic expression of geologic structure - Tertiary basins of Alaska.

(1) Objective - To demonstrate in relatively inaccessible terrain the utility of radar geomorphic studies and to relate geomorphic features to underlying geologic structure. Ultimate aim will be the definition of targets for petroleum exploration.

(2) Approach -

(a) Acquire aircraft radar data and prepare a geomorphic map from imagery. The geomorphic map will be based on and include lineation, slope distribution, drainage patterns, terrain texture, and topographic profiles. Correlate geomorphic and geologic data whenever it is possible to do so.

(b) Compare radar-derived geomorphic maps with the published maps.

(c) Field check the geomorphic maps and determine their reliability.

(3) Sensors - Multipolarized, multifrequency radar imagery is required; however, specific parameters of the system are not defined because of lack of data.

(4) Test sites - Tertiary basins in Alaska. Major basin is centered at approximately 65° N. latitude and 140° W. longitude.

(5) Frequency of coverage - Basically, one-time coverage with initial consideration given to seasonal and time constraints. For the first time, spring, summer, and fall coverage is desired.

d. Geomorphic and geologic analysis - Coastal marsh and swamp environments.

(1) Objective - To demonstrate applicability of dual-/cross-polarized, multifrequency radar for geomorphic/geologic analysis of wetland environments.

(2) Approach -

(a) Obtain multipolarized, multifrequency radar imagery at the time of field data collection.

(b) Make quick-look analysis of data and take into field (helicopter support preferred) to check possible problem interpretive areas.

(c) Do more detailed interpretation based on published data and on "before and after" field data.

(3) Sensors - A dual-/cross-polarization, multifrequency aircraft-mounted radar. Specific bands are not suggested because the data needed to draw conclusions are not available. However, the broad band between the K- and L-band will probably provide the most information. Spacecraft-mounted radar to be used for followup.

(4) Test site - Lower Atchafalaya River Basin and Atchafalaya Bay coastal region. Center geographic coordinates are 30°00' N., 91°30' W.

(5) Frequency of coverage - Initially, seasonal but not required continually.

(6) Season and time constraints - Signal dependence on vegetation relationship to seasonal temperature and hydrologic changes necessitates coverage from at least two, and probably four, times of the year.

Monitoring terrain alterations.- Radar utilized as a change-monitoring device has obvious value in its capability for all-weather, day or night surveillance. Early detection of erosion problems, either on land or at the land-sea interface, facilitates immediate corrective action, with the result that the destruction of valuable land is prevented and the probability of financial losses is reduced. Only one sensor, radar, has such a monitoring capability - a capability postulated but not proven. Only a satellite-borne system is financially feasible, and a demonstration of such a capability would suggest to the scientific community numerous possibilities for utilization of the system in monitoring ongoing geologic processes.

The proposed missions (aircraft and spacecraft experiments) are basically for mapping purposes and emphasize the all-weather, day or night capability of the SLAR. Additionally, a study of resolution requirements for these applications should be conducted. The following experiments are proposed.

1. Soil erosion, lumbering effects.

a. Objective - Determine and monitor the soil erosion effects caused by various lumbering practices, with the ultimate objective of determining the method least likely to produce detrimental terrain modification.

b. Approach -

(1) Image the test site area with radars of various frequencies. Use various incident angles and observe the area during the four seasons. Use image enhancement techniques to extract information.

(2) Develop a program for continuous monitoring of lumbering operations and early detection of soil erosion problems.

(3) Determine the feasibility of such monitoring of small-scale effects by spacecraft radars.

c. Sensors - Very high frequency (vhf), JPL L- and X-band multi-polarization SAR.

d. Test site - Redwood National Park, California. Corner coordinates are as follows.

34°00' N., 81°00' W.

33°15' N., 79°15' W.

32°00' N., 81°00' W.

32°45' N., 82°00' W.

e. Frequency of coverage - Once in January or February, once during summer months.

2. Monitoring coastal processes and change - U.S. west coast.

a. Objective - To monitor coastal processes during and immediately following major storms, when the greatest change occurs and the regions are masked by cloud cover.

b. Approach -

(1) Establish five test sites along the coast encompassing different conditions (dunes, cliff, estuarine/river mouth, marsh, and culturally influenced).

(2) Establish a time-line data base using available published data, aerial photography, and K-band radar (1965) for determining long-range changes.

(3) Acquire aircraft radar data from two opposite aspect angles (both parallel to coastline) during several winter storms, when the major coastal changes take place. Collect field data at same time.

(4) Overlay data in two time sequences for change detection on long- and short-term basis.

(5) Use image-processing techniques to "stretch" the low-return areas from water and open sand and thus increase image information.

(6) Use image enhancement techniques to combine data gathered in a different time, polarization, and frequency format.

c. Sensors - Multifrequency, multipolarized, multilook imaging radar must be flown as an attempt to determine the best combination of these image parameters required for coastal investigations.

d. Test sites - Specific test sites have not been selected. Five sites would embrace different natural and cultural environments.

e. Frequency of coverage - Both remote-sensing and field data need to be acquired before, during, and following several major storms (hopefully of different magnitudes and coming from different directions). This acquisition would be followed by a continuing program in which data would be acquired at a preset interval, with greater frequency of coverage coming during the period of major storms (winter).

f. Season and time constraint - The initial coverage is strongly seasonal and time dependent. Time of data acquisition will be storm dependent.

Terrain-sensor interaction studies.- The second objective is to improve definition of terrain-sensor interaction with variation in system and terrain parameters. Of specific interest are frequency-roughness and polarization-microrelief relationships and the isolation of the effect of dielectric constant variations on the return signal. Regardless of environment, but particularly in arid and semiarid regions, the configuration of fragments of a residual cover is indicative of the nature of the underlying rock material and, thus, may aid considerably in the delineation of geologic units. Where bare rocks are exposed at the surface, their weathering characteristics are diverse; and the surface configuration, as well as the degree of weathering and resulting contrast in topography, aids in identification and mapping. Of importance in such discrimination is an understanding of the effect of variations, polarization, and wavelength on the separation of units as expressed in the resulting image. A singular study (ref. 4-20) on the value of polarization in a single frequency has provided positive evidence that polarization orientation is important. Several studies (refs. 4-24, 4-16, and 4-19) concerned with rock discrimination relative to radar frequency have pointed to the value of multifrequency systems. Further studies in diverse terrains with multipolarization, multifrequency systems are needed to determine the optimum parameters for a wide range of terrain studies.

Although a great deal has been done to define the effect on the return signal of soil moisture content at a range of frequencies, only preliminary studies have been made to isolate the effect of saline content on the dielectric properties of surficial materials and determine the effect on the return signal.

Well recognized in several areas in the United States today is the problem of saline pollution through circulation of salt water to the surface. Any attempt to correct such conditions initially requires the identification of areas of pollution, as well as continued monitoring of the shape or size of the polluted area. Preliminary laboratory and Skylab microwave data acquired over the Great Salt Lake Desert indicate that saline content can strongly influence the radar return signal. Particularly in areas where climatic conditions pose problems for aerial monitoring, radar, with a capability to detect subtle contrasts in saline content of surface and ground water, should prove invaluable. If pollution has affected the vegetation pattern, near-IR photography should detect the contrast between contaminated and uncontaminated areas. However, for repetitive monitoring in order to detect change and for all-season monitoring when vegetation contrasts are largely eliminated, radar shows potential for being the prime sensor in such a study.

Theoretical modeling and laboratory, ground-based, and aircraft experiments to determine the effects of saline seeps on the radar backscatter have been covered in the "Vegetation Resources Program Plan" section and, hence, will not be repeated here.

To acquire an operational capability in this application area, the following tasks are recommended.

1. Task A - Ground-based experiments. With the exception of acquisition of ground data simultaneously with overflights, ground-based experiments are required only for the polarization signature study, for which the X-band polarization modulation system mounted on a mobile ground platform will be utilized. A description of this study may be summarized as follows.

a. Objective - Determine backscatter polarization signatures for the purpose of identifying surface-roughness types and vegetation.

b. Approach - Reassemble the X-band polarization modulation systems, mount the radar on the cherry picker and truck, and deploy the sensor at selected sites.

c. Sensors - X-band short-pulse radar, polarization modulation antenna, cherry picker, and truck.

d. Availability - The radar system was completed in 1972, some data were obtained, and the system was disassembled, with some components going to the X-band imaging radar. The antenna, which is a major component, is in storage; the status of the logic and modulator is uncertain. However, the system could probably be reassembled at a relatively low cost.

e. Test sites - The truck would go to various sites - such as Death Valley, California, crop identification sites (Kansas), snow cover sites, etc. - to obtain polarization signatures.

f. Frequency of coverage - In areas where the scatter changes with season, the truck would revisit the sites at appropriate times.

g. Schedule - One year is needed to assemble the sensor; included will be the radar, the cherry picker, the truck data-storage device, and the system for processing data. One year is assigned to accumulating the signature data.

h. Cost estimate -

(1) Antenna - Available, no cost.

(2) Cherry picker - Available, no cost.

(3) Truck - Available, no cost.

(4)	Radar - Reassemble some components,	$150 000
(5)	Data storage -	40 000
(6)	Data-processing software -	30 000
(7)	Operations (1 year) -	60 000
		$280 000

2. Task B - Aircraft and spacecraft experiments.

a. Death Valley, California, backscatter modeling -

(1) Objective - Determine the effect of surface roughness on radar backscatter at various wavelengths. Establish a calibration site for all radar systems.

(2) Approach - Measure surface roughness with surface devices such as stereophotographs and profile gages; measure dielectric properties, water content, and gravel sizes. Conduct aircraft flights in which scatterometers and imaging radars are used. Conduct spacecraft radar observations on the site.

(3) Sensors -

(a) Three-frequency (0.4, 1.6, and 13.3 GHz) scatterometer (JSC).

(b) Passive microwave (1.4 GHz) radiometer (JSC).

(c) IR spot radiometer (JSC).

(d) L- and X-band imaging radars, vhf (JPL).

(e) Seasat SAR, L-band (JPL).

(4) Test site - Death Valley, California.

(5) Frequency of coverage - Not applicable.

(6) Season and time constraints - Not applicable.

b. Polarization studies - Pisgah Crater, California, and central Utah.

(1) Objective - To determine the polarization-frequency interrelationships of the radar return from natural geologic terrains.

(2) Approach - Review previous data and obtain X- and L-band imagery (and any other available) with HH-, VV-, and cross-polarization. Surface configuration, composition, and moisture data will be acquired during overflights; imagery will be evaluated annually and in various combined formats; and the correlation of radar signature and terrain characteristics will be investigated.

(3) Sensors - L-band and X-band SAR, aerial cameras.

(4) Test sites - Pisgah Crater, California, and San Rafael Swell, Utah.

(5) Frequency of coverage - Dual coverage.

(6) Season and time constraints - Not applicable.

c. The role of salt content in control of SAR return signature from a playa or desert area, Great Salt Lake Desert, Utah -

(1) Objective - Develop a mechanism for determining the salt content of desert and playa soils with the use of SAR imagery.

(2) Approach - Identify, from ongoing studies, areas of contrasting salt content, lithologies and roughness, and vegetative cover for coverage with JPL X- and L-band radar. Identify, insofar as possible, the contribution of roughness, soil composition, vegetation, soil moisture, and salt content to the return signal.

(3) Sensors - JPL X- and L-band radar with multipolarization capability. Aerial camera for control, feature identification, and sample-site location.

(4) Test site - Great Salt Lake Desert, Utah; 100- by 200-km flight lines as defined on accompanying map.

(5) Frequency of coverage - Two flights.

(6) Season and time constraints - August and December during periods of relative surface dryness.

d. Comparative study of Landsat and SAR imagery -

(1) Objective - A comparison between Landsat MSS imagery and two-polarization JPL X- and L-band SAR imagery to document any unique (other than cloud penetration) capability of the SAR and, at the same time, compare the relative data content of X- and L-band imagery for two polarizations.

(2) Approach - Selection of the site will be based on the intensity and diversity of origin of structural (primarily linear or curvilinear) features identified within the area in eastern Kansas now subject to intense scrutiny for evidence of recent faulting and/or earthquake activity. SAR imagery and near simultaneously acquired Landsat imagery would be independently evaluated for structural content, and the cause for correlation or lack of correlation with terrain features would be determined. Unique capabilities of SAR and the reason for such should be expected to be established.

(3) Sensors - JPL X- and L-band multipolarization SAR, Landsat imagery.

(4) Test sites - Kansas, east of Nemaha Uplift (precise definition on basis of results of current investigation).

(5) Frequency of coverage - Seasonal (four times). If feasible, winter coverage during period of snow cover for maximum enhancement of features on Landsat (MSS) imagery.

(6) Season and time constraints - Near simultaneous acquisition of SAR and Landsat imagery. Winter scene with snow cover preferable.

Development Plan

Figure 4-7 is a mineral resources and geologic applications development plan, in a flow chart format, summarizing the major steps between the present status of each application area and the ultimate goal - i.e., operational capability. The associated schedules of aircraft and spacecraft experiments for each of the major application areas are summarized in figure 4-8, the corresponding resource requirements are summarized in table 4-9, and the test site locations are indicated in figure 4-9.

Summary and Recommendations

The proposed experiments, although somewhat diverse in immediate objectives, are basically designed to achieve the following two long-range objectives.

1. To demonstrate utilization of active microwave technology in a wide range of geologic investigations in a wide range of environments

a. To define lineament or other structural or terrain features not subject to short-term change

b. To monitor natural or man-induced physical or chemical terrain alteration

2. To better define target-terrain interaction with system-terrain parameter variation

Specifically, it is recommended that NASA place renewed emphasis on the definition of optimum system parameters for a wide range of geologic investigations, and special emphasis on the development of the polarization capability of the radar measurement system. At the same time, applications research and demonstration should continue in order to further industrial as well as governmental understanding and acceptance of radar as a significant exploration tool.

OCEANOGRAPHIC APPLICATIONS PROGRAM PLAN

Introduction

The subpanel on oceanographic applications recognizes the potential value of imaging-radar experiments from the Shuttle in the development and demonstration of techniques for ocean applications. Certainly, those people involved in oceanographic work look forward to opportunities to make use of these data. It is the present consensus of the oceanographic community that the Shuttle represents a desirable, but not indispensable, link between present technology and that required to implement an operational system of oceanographic satellites deploying imaging radar. It now appears that SAR data processing, rather than SAR sensor development, is the key problem to be solved. Table 4-10 is a summary of progress, observational requirements, and relationships to other sensors pertaining to each major oceanographic application area.

Approach

For several years, a representative cross section of the oceanographic community has been meeting on a regular basis to plan experiments in connection with Seasat. The members of this subpanel, many of whom participated in these meetings, do not believe that it is desirable to attempt to summarize these plans here. These plans have been through several iterations, such as those found in the following internal NASA reports.[6]

Seasat-A Science Contributions

Seasat-A Phase B Study Report

EODAP[7] Program Plan (in revision)

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[6]Not available to public.
[7]Earth and Ocean Dynamics Applications Program.

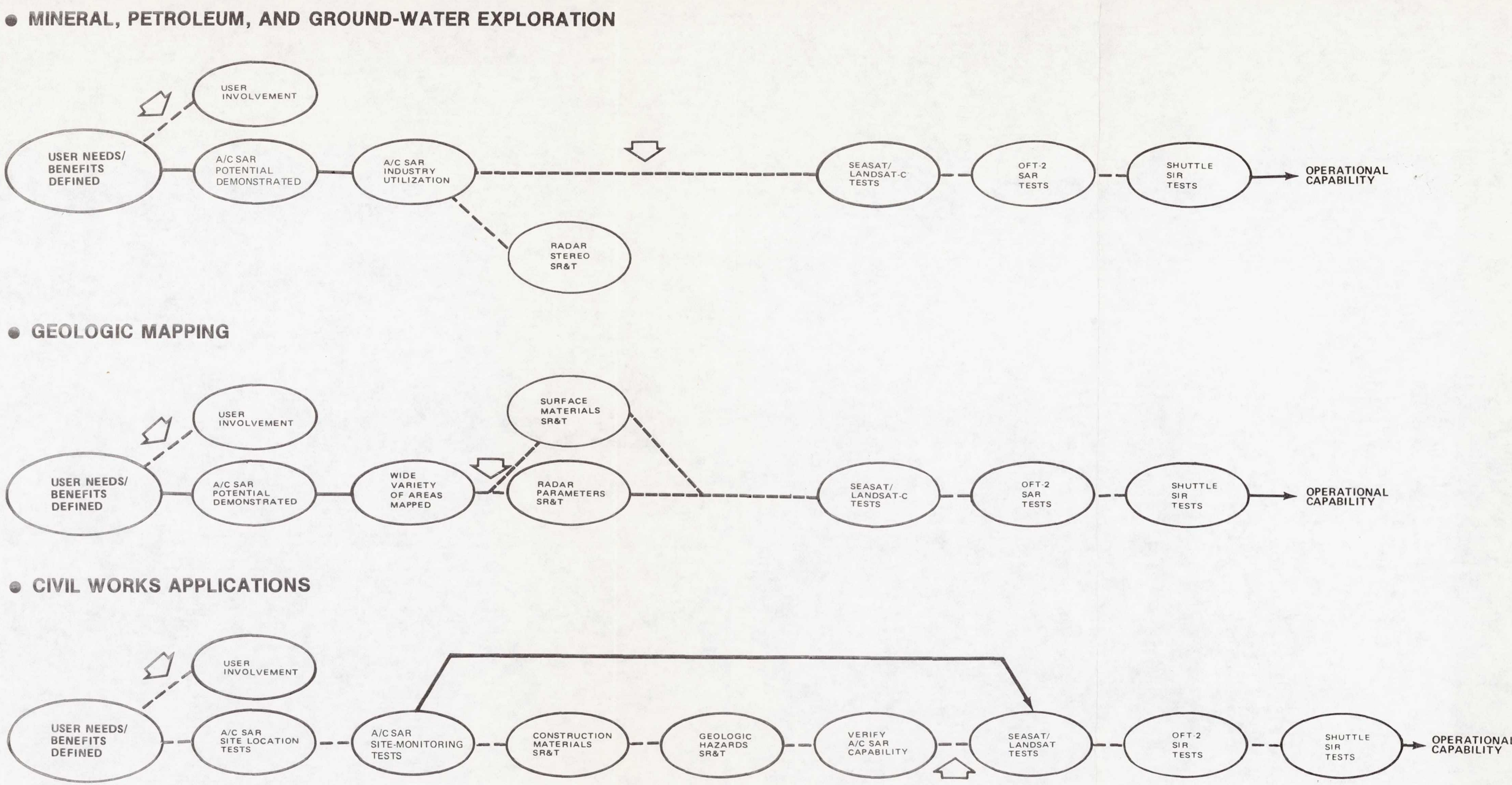

Figure 4-7.- Mineral resources and geologic applications development plan.

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Application area	Fiscal year 1976–1978: Aircraft experiments	Fiscal year 1979–1980: Spacecraft experiments
1. Mapping structural features		
a. Mineral and petroleum exploration - central Arkansas	▽ A D △	Seasat △ OFT-2 △
b. Geologic analysis - Eastern Coastal Plain	OG A D △	Seasat △ OFT-2 △
c. Geomorphic study - Alaska	▽ A D △	Seasat △ OFT-2 △
d. Geomorphic analysis - coastal and swamp	▽ A D △	Seasat △ OFT-2 △
2. Monitoring terrain alterations		
a. Soil erosion-lumbering effects	▽ A D △	Seasat △ OFT-2 △
b. Monitoring coastal processes	▽ A △	Seasat △ OFT-2 △
3. Terrain-sensor interaction studies		
a. Death Valley, California, backscatter modeling	OG A D A D △	Seasat △ OFT-2 △
b. Polarization study - Pisgah Crater, California	▽ A D △	
c. Salt content effects - Salt Lake Desert, Utah	OG A D A D △	
d. SAR/Landsat comparative study	OG A D △	

Key:

A - Aircraft flights complete
D - Data read/analysis complete
OG - Ongoing
▽ - Initiate
△ - Reports, project complete

Figure 4-8.- Mineral resources and geologic applications/active microwave activities.

TABLE 4-9.- MINERAL RESOURCES AND GEOLOGIC APPLICATIONS FUNDING REQUIREMENTS

Application area	Fiscal year				
	1976	1977	1978	1979	1980
Ground-based experiments					
Polarization signature study	$150 000	$140 000	$ 90 000	$ 60 000	--
Aircraft experiments					
Mapping structural features					
Mineral and petroleum exploration - central Ark.	20 000	60 000	50 000	60 000	$ 60 000
Geologic analysis - eastern Central Plain	Ongoing	80 000	50 000	60 000	60 000
Geomorphic study - Alaska	--	80 000	120 000	60 000	60 000
Geomorphic analysis - coastal and swamp	--	80 000	60 000	60 000	60 000
Monitoring terrain alterations					
Soil erosion - lumbering effects	20 000	60 000	50 000	50 000	40 000
Monitoring coastal processes	--	80 000	100 000	60 000	60 000
Terrain-sensor interaction studies					
Death Valley, Calif., backscatter modeling	Ongoing	80 000	40 000	60 000	60 000
Polarization study - Pisgah Crater, Calif.	--	80 000	60 000	--	--
Salt content effects - Great Salt Lake Desert, Utah	Ongoing	80 000	60 000	--	--
SAR/Landsat comparative study	Ongoing	50 000	60 000	--	--
Total resources	$190 000	$870 000	$740 000	$470 000	$400 000

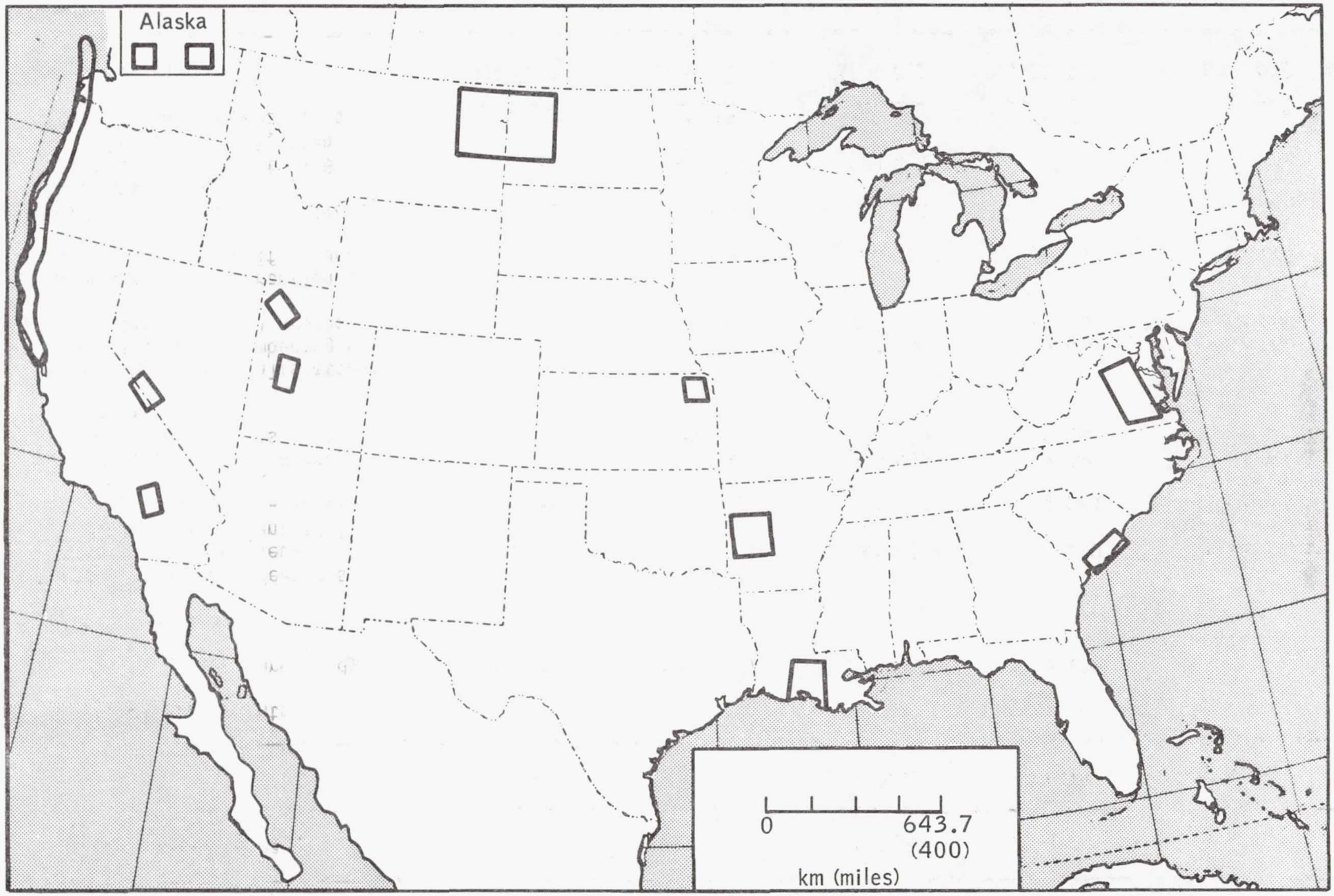

Figure 4-9.- Mineral resources and geologic applications test sites.

TABLE 4-10.- OCEANOGRAPHIC APPLICATIONS SYSTEMS REQUIREMENTS

Application	Role[a]			Wave-length,[b] cm	Interpretation resolution, m		Nadir angle, deg	Polar-ization type	Revisit interval, hr	Status[c]	Priority[d]	Comments
	Active microwave	Passive microwave	Visible/IR		Desire	Accept						
Ocean waves and sea state monitoring	P	C	N	1 to 30 MF	3	25	0 to 25	HH, VV	6 to 12	PS	H	Extensive experiments in progress
Sea ice monitoring	P	P	N	1 to 30 MF	25	25	0 to 25	HH/VV/cross	6 to 12	PC	H	Proven sea ice capability
Icebergs and ship monitoring	P	S	N	1 to 30 MF	10	25	25 to 60	HH/VV/cross	6 to 12	SE	M	Experiments in progress
Oil pollution monitoring[e]	P	S	S	1 to 30 MF	25	25	0 to 25	VV, cross	6 to 12	PC	M	Proven oil spill detection

[a]The role symbols are defined as follows.
- P - prime sensor
- C - complementary sensor
- S - supportive sensor
- N - not needed

[b]MF = multifrequency.

[c]The status symbols are defined as follows.
- PC - proven capability
- SE - strong evidence of capability
- PS - potential suggested by experimentation

[d]The priority symbols are defined as follows.
- H - high priority
- M - medium priority

[e]Extensive testing underway by Coast Guard.

Seasat-A Project Plan

SAR Experiment Plan (in preparation)

NOAA Seasat-A Program Development Plan

Development Plan

Figure 4-10 is an oceanographic applications development plan, and figure 4-11 presents summary schedules.

Summary and Recommendations

The major application areas were rated with respect to priority and feasibility as follows.

High:

1. Ocean waves and sea state monitoring and forecasting

2. Sea ice monitoring

Medium:

1. Iceberg monitoring and ship navigation routing

2. Oil pollution monitoring

3. Coastal structure placement

Because most of the parameters of interest in oceanography and ship monitoring change significantly from hour to hour, the data from a short-lived-satellite imaging radar system have no operational value in themselves. For the oceanographer, the usefulness of the SIR program is with respect to advancing the instrument's development and conducting space engineering/ environmental tests. Hence, it is recommended that NASA place special emphasis on these aspects.

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● OCEAN WAVE AND SEA STATE MONITORING

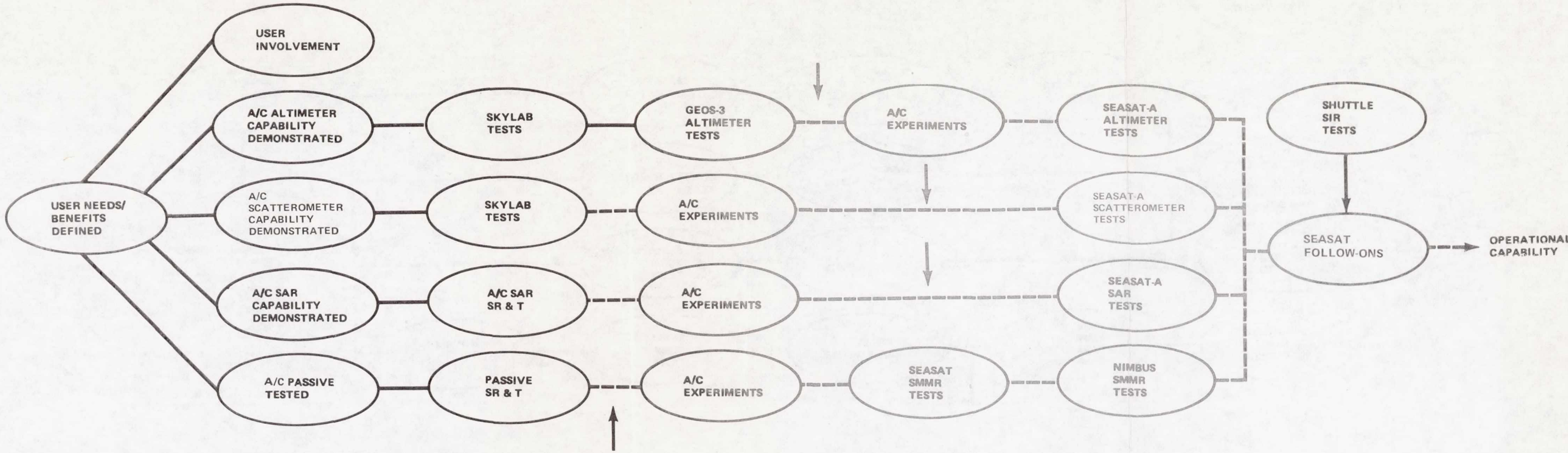
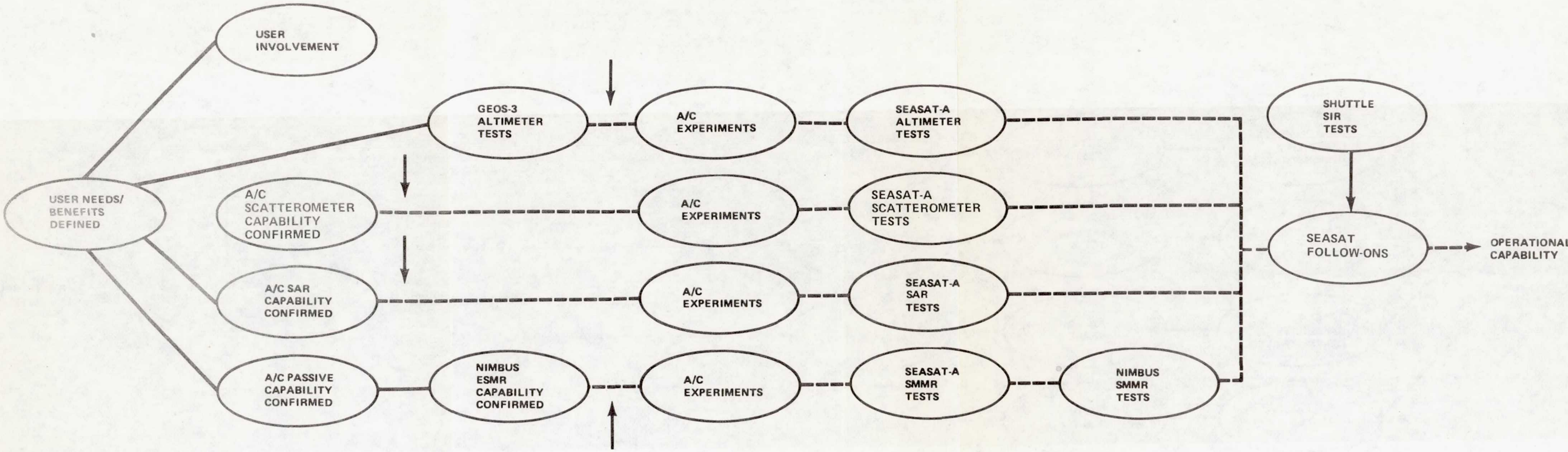


Figure 4-10.- Oceanographic applications development plan.

● SEA ICE MONITORING



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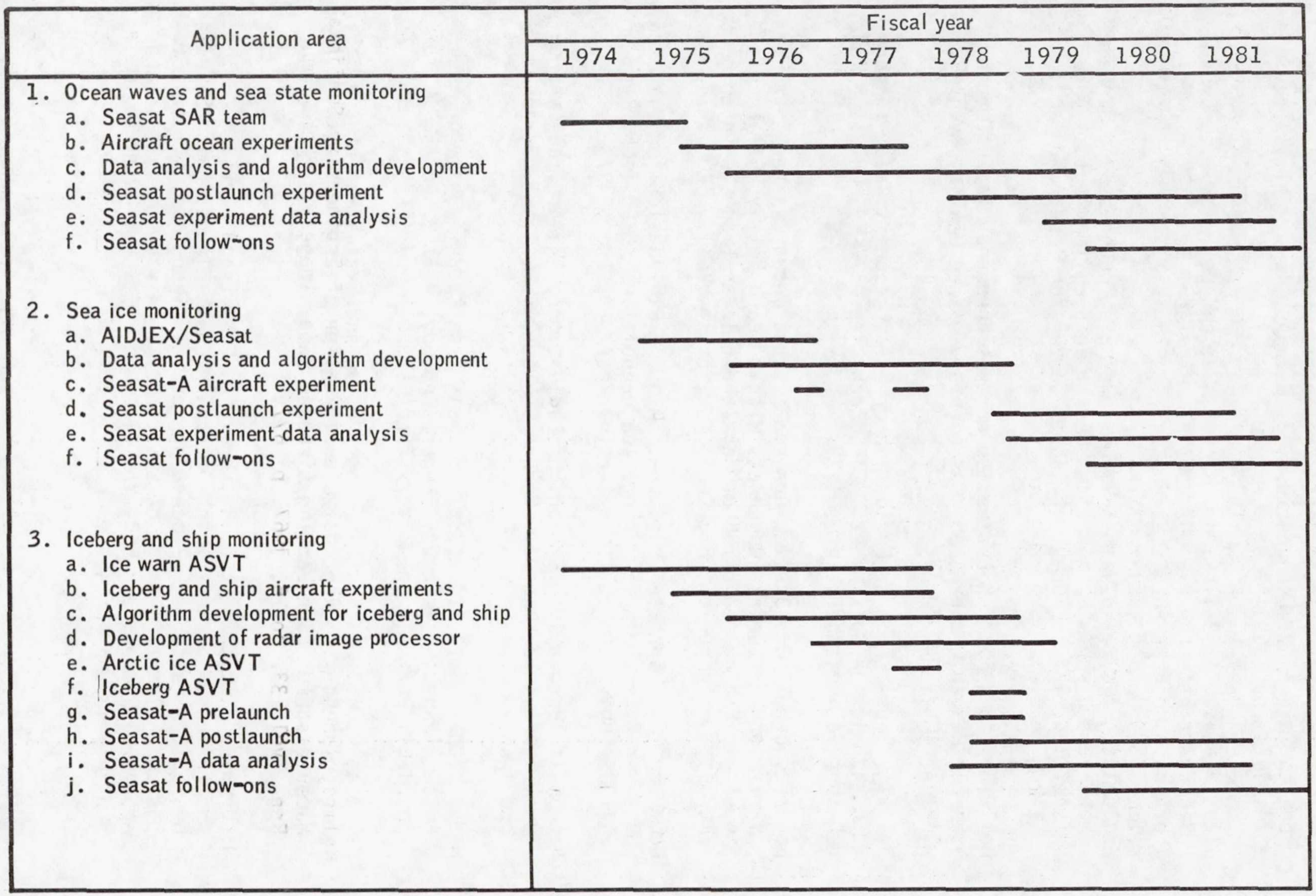

Figure 4-11.- Oceanographic applications/active microwave activities.

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